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The Role of Technology Transfers in China’s Defense Technological and Industrial Development and the Implications for the United States

5 February 2019

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Abstract

China's defense science, technology and innovation system has engineered a remarkable turnaround in its fortunes in the past two decades. External technology and knowledge transfers and the defense industry's improving ability to absorb these inputs and convert into localized output has played a central role in accounting for this progress. China has pursued an intensive campaign to obtain defense and dual-use civil-military foreign technology transfers using a wide variety of means from spending heavily on importing large amounts of technologies and engaging in joint collaboration to the use of more nefarious means, such as industrial and cyber espionage.

A number of questions are addressed. How has China been able to exploit access to foreign defense and dual-use technologies and knowledge and how has the defense industry been able to assimilate these inputs? How successful have Chinese efforts at defense technological re-innovation been, and how does this compare with and complement its longer-term efforts at original innovation? How, and to what extent do recent Chinese defense technological innovations support the ability of the People's Liberation Army (PLA) to protect the country's expanding international interests? What are the challenges that confront the Chinese defense industry in its continuing efforts to modernize and support the PLA in its efforts to be able to fight and win future wars?

An analytical framework to examine the relationship between technology transfers and China's defense innovation is put forward. The concept of absorptive capacity is explored along with mapping the imitation to innovation environment to provide the context and benchmarks in which to identify the Chinese defense industry's progress. Eight categories of imitation and innovation are defined in the typology beginning with duplicative imitation through to radical innovation. China has put forward a three-step strategy to indigenous innovation: introduction, digestion, assimilation and re-innovation.

Three case studies provide detailed insights into China's military and commercial technological development arc, the central role that foreign technology transfers play, and the difficult struggle with absorbing these capabilities: 1) Acquisition of Britain's Spey Mk202 jet engine; 2) advanced imitation of the Russian Su-27 jet fighter; and 3) China's involvement in producing the Boeing 787 and how this has helped in the development of China's homegrown C919 airliner. There is also analysis of the impact of this technology absorption by the Chinese defense industry on the enhancement of the PLA's force projection capabilities, especially on the aviation, naval, and precision strike sectors.

The principal challenges facing China's defense industry in its goal of becoming a world-class original innovator will also be discussed along with examination of Xi Jinping's efforts to pivot from re-innovation to original homegrown innovation. The paper concludes by looking at the global implications of an increasingly innovative Chinese defense establishment, focusing on intensifying U.S.-China technological competition.

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Introduction

China's defense science, technology and innovation system has engineered a remarkable turnaround in its fortunes in the past two decades. This progress was proudly on display at the grand military parade commemorating the 70th anniversary of China's victory over Japan in World War II in September 2015 and at the 90th anniversary of the PLA's founding in August 2017. New generations of state-of-the-art weapons systems were shown off from across virtually the entire defense technological spectrum from aviation and ordnance to electronics and missiles.

What accounts for this revival of the Chinese defense industry? Structural reforms, increased investment, high-level leadership attention, a worsening threat environment, improved corporate performance, and the cultivation of a higher quality scientific workforce are some of the principal explanatory factors. But this paper argues that the role of external technology and knowledge transfers and the defense industry's improving ability to absorb these inputs and convert into localized output has had the biggest impact. China is pursuing an intensive campaign to obtain defense and dual-use civil-military foreign technology transfers using a wide variety of means. This ranges from spending heavily on importing large amounts of technologies and engaging in joint collaboration to the use of more nefarious means, such as industrial and cyber espionage.

This paper addresses a number of questions. How has China been able to exploit access to foreign defense and dual-use technologies and knowledge and how has the defense industry been able to assimilate these inputs? How successful have Chinese efforts at defense technological re-innovation been, and how does this compare with and complement its longer-term efforts at original innovation? How, and to what extent do recent Chinese defense technological innovations support the ability of the People's Liberation Army (PLA) to protect the country's expanding international interests? What are the challenges that confront the Chinese defense industry in its continuing efforts to modernize and support the

PLA in its efforts to be able to fight and win future wars?

This paper begins by offering an analytical framework to examine the relationship between technology transfers and China's defense innovation. The concept of absorptive capacity will be explored along with mapping the imitation to innovation environment to provide the context and benchmarks in which to identify the Chinese defense industry's progress. Eight categories of imitation and innovation are defined in the typology beginning with duplicative imitation through to radical innovation. China has put forward its own three-step strategy to indigenous innovation: introduction, digestion, assimilation and re-innovation (IDAR), which is advanced imitation; integrated innovation; and original innovation. IDAR is currently the most relevant model guiding the Chinese defense industry's technology development and the paper will examine this approach in detail.

Three case studies of the painstaking and at times baffling acquisition of the British Spey Mk202 jet engine and the advanced imitation of the Russian Su-27 jet fighter will provide insights into China's military technological development arc, the central role that foreign technology transfers play, and the difficult struggle with absorbing these capabilities. There will also be an analysis of the impact of this technology absorption by the Chinese defense industry on the enhancement of the PLA's force projection capabilities. Particular attention will be paid to the aviation, naval, and precision strike sectors.

The third case study is of US aviation-related technology transfers to China and how it has helped in the development of China's commercial airliner industry. Of particular focus is China's involvement role in the production of the Boeing 787, and the associated technology transfer. Many of the technologies incorporated into China's homegrown C919 airliner, including composite materials and avionics systems, were originally developed, in large part, by the US Department of Defense (DoD), its industry partners, and its allies.

The principal challenges facing the Chinese defense industry in its long-term goal of becoming a world-class original innovator will also be discussed and this will be followed by an examination of the efforts under Xi Jinping's rule to pivot from re-innovation to the pursuit of original homegrown innovation. The paper concludes by looking at the global implications of an increasingly innovative Chinese defense establishment, particularly focusing on intensifying U.S.-China technological competition.

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Analytical Framework to Examine the Relationship Between Technology Transfers and Chinese Defense Innovation

The contemporary mainstream definition of innovation is the introduction of a novel product or process through invention and/or commercialization. But another important attribute of innovation that is overlooked is the combination of existing and/or new knowledge that results in an improved output. Joseph Schumpeter, one of the pioneers in the study of innovation, identified innovation as combining already available products and processes in a novel way that leads to new outcomes.[1] Bengt-Åke Lundvall also supports this notion of innovation as "a new use of pre-existing possibilities and components."[2]

This practice of combining foreign technology and knowledge with domestic capabilities that generates improvements and promotes national development is a well-proven roadmap for successful technological catching up that has been employed through the ages. This includes many states that have gone on to become advanced technology powers today. France and Prussia in the 18th and 19th centuries, for example, relied on imports of British industrial technology that they subsequently reverse engineered and incorporated in their industrialization drives.[3]

The successful technological catching up by Japan and South Korea between the 1950s and 1990s can also be attributable to their implementation of highly effective industrial absorption and combination policies.[4] Of particular

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[1] Joseph Schumpeter, ***The Theory of Economic Development*** (Cambridge, MA: Harvard University Press, 1934), p65-68.

[2] Bengt-Åke Lundvall, ***National Systems of Innovation*** (London: Anthem Press, 2010), p9.

[3] Chris Freeman and Luc Soete, ***The Economics of Industrial Innovation*** (Cambridge, MA: MIT Press, 3rd Edition, 1993), 297-298 and Margaret Bradley, "Examples of Industrial and Military Technology Transfer in the Eighteenth century ", ***Documents Pour L'Histoire des Techniques,*** No.19, Online Version 21 June 2011, http://dht.revues.org/1340

[4] See Hyungsub Choi, "Technology Importation, Corporate Strategies, and the Rise of the Japanese Semiconductor Industry in the 1950s", ***Comparative Technology Transfer and Society,*** Vol. 6, No. 2, August 2008; Moon Young Chung and Keun Lee, "How Absorptive Capacity is Formed in a Latecomer Economy: Different Roles of Foreign Patent and Know-how Licensing in Korea", ***World Development***, Vol. 66, 2015, pp678-694; Linsu Kim,

importance was the utilization of ‘know-how’ contracts, in which Japanese and Korean firms signed agreements with foreign companies that allowed them access to manufacturing capabilities, personnel exchanges, and blueprints. This provided the knowledge and learning to engage in reverse engineering, which is a critical skill needed for catching up.

Reverse engineering is a widely accepted international practice as long as the products being copied are legitimately acquired.[5] This is the vital difference between the civilian and military spheres. Product access in the civilian domain is far more permissive than in the defense sector, where products are subject to tight export controls, especially against potential adversaries. For states that are barred from access to external military and sensitive technologies but are determined to acquire them, their only choices are to develop these capabilities by themselves, obtain these technologies through subterfuge, or to pursue both goals at the same time.

The Soviet Union stands out as the chief exponent of this parallel approach of indigenous development coupled with an extensive industrial espionage effort that was undertaken throughout the entire lifespan of the Soviet regime, and which also appears to have continued afterwards. As Katherine Sibley notes in a study of Soviet industrial espionage against the U.S. in the 1930s and 1940s, “this effort materially supported the industrial and technological development of the Soviet Union, particularly in the area of aircraft and weapons technology, and vitally assisted the war effort.”[6]

Soviet industrial espionage efforts intensified in the post-1945 Cold War era, and especially in its final decades as the Soviet defense industry fell increasingly behind the technological arms race with the U.S. and its Western allies. One of the biggest operations that the Soviets mounted to address this widening gap occurred

Absorptive Capacity and Industrial Growth: A Conceptual Framework and Korea’s Experience (Korea Development Institute, Seoul, 1991); and Kenkichiro Koizumi, “The Development of Industrial Technology in Japan: Will vs. Absorptive Capacity”, ***Minerva,*** No.33, 1995, pp19-35.

[5] Pamela Samuelson and Suzanne Scotchmer, “The Law and Economics of Reverse Engineering”, ***Yale Law Journal***, Vol.111, No.7, May 2002.

[6] Katherine A. S. Sibley, “Soviet Industrial Espionage Against American Military Technology and the US Response, 1930–1945,” ***Intelligence and National Security,*** Vol. 14, No. 2 (1999), pp94-123.

between the early 1970s and early 1980s when Soviet agents successfully acquired huge amounts of Western defense technology. A 1985 CIA assessment, based on classified Soviet documents, described “a massive, well organized campaign by the Soviet Union to acquire Western technology illegally and legally for its weapons and military equipment projects…Virtually every Soviet military research project—well over 4,000 each year in the late 1970s and over 5,000 in the early 1980s—benefits from these technical documents and hardware.”[7] The scale and intensity of the Soviet effort can be likened to the traditional industrial age espionage equivalent of China’s present cyber-espionage campaign in the digital era.[8]

The CIA assessment judged that stolen Western technology could reduce the Soviet weapons research and development cycle by up to two years for research projects in an advanced stage of development. For projects in an earlier stage of research, the cycle could be lessened by as much as five years. The report concluded that, “this considerably shrinks overall research time, reduces the amount of resources devoted to weapon systems research, and allows diversion of those resources to other Soviet military research projects”.[9]

The experiences of Japan, South Korea, and the Soviet Union have had a major influence in the thinking and making of contemporary Chinese national and defense industrial and innovation strategies. Innovation as recombination is at the heart of how the Chinese authorities approach the pursuit of science, technology, and innovation in the 21st Century. This is spelled out in the 2006-2020 Medium & Long Term Science and Technology Development Plan (MLP) that defines indigenous innovation as the promotion of original innovation by re-assembling existing technologies in different ways to produce new breakthroughs and absorbing and upgrading imported technologies.[10] The parallel 2006-2020

[7] Central Intelligence Agency, ***Soviet Acquisition of Militarily Significant Western Technology: An Update***, September 1985.
[8] See Jon Lindsay, Tai Ming Cheung, and Derek Reveron (Eds), ***China and Cybersecurity*** (Oxford; Oxford University Press, 2015).
[9] ***Soviet Acquisition of Militarily Significant Western Technology***, Op Cit, p8.
[10] State Council, ***Guidelines for the Medium- and Long-Term National Science and Technology Development Program*** (2006-2020), June 2006. See also Kirsten Bound et al, ***China’s Absorptive State*** (London: Nesta, October 2013.)

Medium and Long-Term Defense Science and Technology Development Plan (MLDP) also refers to the importance of recombination by implementing policies and measures that support the importation, absorption, and re-innovation of foreign technology.[11]

To successfully combine foreign and domestic technologies, catch-up countries need to have an effective absorptive capacity, which refers to the ability of a country to recognize, assimilate, and utilize new and external knowledge.[12] Related but distinct from absorption is innovative capacity, which is the ability of a country to carry out original research and development that leads to the creation and commercialization of novel technology and knowledge. Innovative capacity primarily relies upon a country's own national innovation system, which means that it needs to have a well-developed set of institutional arrangements and organizations ranging from universities and research institutes that engage in scientific research to governance regimes that incentivize and support the innovation process from discovery to commercialization.

While absorptive and innovation capacity are very different in nature, there is considerable overlap between them and they should be viewed as co-existing alongside each other rather than as opposing forces. The relative importance of absorptive and innovative capacity varies depending on the technological nature of a country. For catch-up countries, absorptive capacity is their principal science and technology capacity for technological development, while innovative capacity is dominant for countries on the innovation frontier. For countries like China that are transitioning from relying solely on imitation as the main means of technological development to also conducting original innovation, absorptive and innovative capacity are in a more balanced alignment.

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[11] Commission of Science, Technology, and Industry for National Defense, ***"Outline of Defense Medium and Long Term Science and Technology Development Plan"*** (国防科技工业中长期科学和技术发展规划纲要), 29 May 2006. See also, "China Unveils Plan for Developing Defense Technologies", ***Xinhua News Agency***, 25 May 2006.
[12] Wesley Cohen and Daniel Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation", ***Administrative Science Quarterly***, Vol. 35, No.1, March 1990. This concept has been widely used in the fields of business management, organizational economics, and developmental economics.

The Concept of Absorptive Capacity and the Imitation to Innovation Typology

A useful framework of analysis developed by Shaker Zahra and Gerard George views absorptive capacity as a dynamic capability embedded in a firm's routines and processes, is geared towards effecting organizational change, and is strategic in nature as it defines a firm's path of development and evolution.[13] While their focus is at the enterprise level, this can also be applied at the state level. They observe that absorptive capacity has four dimensions that can be grouped into two categories:

- **Potential absorptive capacity** allows organizations to be receptive to the absorption of external sources of knowledge, but does not mean that they will be able to successfully exploit this knowledge. There are two key components of potential absorptive capacity: 1) **Acquisition** signifies the capability to identify and acquire externally generated knowledge that is critical to operations; and 2) **Assimilation** refers to the routines and processes that allow organizations to analyze, process, interpret, and understand the information obtained from external sources.
- **Realized absorptive capacity** is the ability of an organization to turn its potential absorptive capacity into actual output. There are two key attributes: 1) **Transformation** denotes a capability to develop and refine the routines that facilitate combining existing knowledge and the newly acquired and assimilated information; and 2) **Exploitation** allows organizations to refine, extend, and leverage existing competencies or to create new ones by incorporating acquired and transformed knowledge into its operations.

In applying the absorptive capacity concept to China's defense S&T system, it is important to recognize the fundamental differences in how the S&T process works in imitation- and innovation-oriented regimes. For imitative countries, research and development is either absent or plays a limited role depending on

[13] Shaker Zahra & Gerard George, "Absorptive Capacity: A Review, Reconceptualization, and Extension", ***Academy of Management Review***, Vol.27, No.2, April 2002, 186.

the degree of imitation that is practiced. There are three general categories of imitation[14]:

- **Duplicative Imitation:** Products, usually obtained from foreign sources, are closely copied with little or no technological improvements. This is the starting point of industrial and technological development for latecomers. The process begins with the acquisition of foreign technology, which then goes directly into production with virtually no technology development or engineering and manufacturing development. The comparable Chinese concept for duplicative imitation is 'introduction' (引进).
- **Creative Imitation:** This represents a more sophisticated form of imitation that generates imitative products with new performance features. Domestic research input is relatively low, but is beginning to find its way into modest improvements in components or non-core areas. The development process becomes more robust with more work done in the technology development and engineering and manufacturing stages. The work here is primarily how to integrate domestic components into the dominant foreign platform.
- **Creative Adaptation:** Products are inspired by existing foreign-derived technologies but can differ from them significantly. This can also be called advanced imitation. One of the primary forms of creative adaptation is reverse engineering. There is considerably more research conducted here than in the creative imitation stage, especially in product or concept refinement, and there is also significantly more effort and work to combine higher levels of domestic content onto an existing foreign platform. The equivalent Chinese term for creative adaptation is 're-innovation' (再创新).

As catch-up countries become increasingly sophisticated in their ability to conduct advanced imitation activities, especially through the building up of homegrown research and development capabilities, they eventually transition into original innovation activity. This can be divided into five categories:

- **Crossover Innovation:** This refers to products jointly developed by Chinese and foreign partners with significant technology and knowledge transfers to the local side that result in the creation of a R&D base able to conduct independent and original innovation activities. However, there is still considerable reliance on foreign countries for technological and managerial input to ensure that projects come to fruition.
- **Incremental Innovation:** This is the limited updating and improvement of existing indigenously developed systems and processes. Incremental

[14] Linsu Kim and Richard Nelson put forward a couple of these categories in their assessment of catch-up countries in East Asia, especially of South Korea. See Linsu Kim & Richard R. Nelson (Eds), ***Technology, Learning, and Innovation*** (Cambridge; Cambridge University Press, 2000), 3-5.

innovation can be the gradual upgrading of a system through the introduction of improved sub-systems but it is also often the result of organizational and management inputs aimed at producing different versions of products tailored to different markets and users, rather than significant technological improvements through original research and development.

- **Architectural Innovation:** This can be distinguished between product and process variants. Architectural product innovation refers to "innovations that change the way in which the components of a product are linked together, while leaving the core design concepts (and thus the basic knowledge underlying the components) untouched."[15] Architectural process innovation refers to the redesign of production systems in an integrated approach (involving management, engineers and workers as well as input from end-users) that significantly improves processes but does not usually result in radical product innovation. Japan between the 1950s and 1990s was a pioneer in architectural process innovation in which major Japanese companies "grew accustomed to the entire production process as a system and to thinking in an integrated way about product design and process design".[16] This was especially the case in the automobile, shipbuilding, and home electronics sectors. The primary enablers are improvements in organizational, marketing, management, systems integration, and doctrinal processes and knowledge that are coupled with a deep understanding of market requirements and close-knit relationships between producers, suppliers, and users. As these are also the same factors responsible for driving incremental innovation, distinguishing between these different types of innovation poses a major analytical challenge. While many of these soft capabilities enabling architectural innovation may appear to be modest and unremarkable, they have the potential to cause significant, even discontinuous consequences through the reconfiguration of existing technologies in far more efficient and competitive ways that challenge or overturn the dominance of established leaders.

- **Component or Modular Innovation:** This involves the development of new component technology that can be installed into existing system architecture. Modular innovation emphasizes hard innovation capabilities such as advanced R&D facilities, a cadre of experienced scientists and engineers, and large-scale investment outlays.

- **Radical Innovation:** This requires major breakthroughs in both new component technology and architecture and only countries with broad-based, world-class R&D capabilities and personnel along with deep financial resources and a willingness to take risk can engage in this activity.

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[15] Rebecca Henderson and Kim Clark, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," ***Administrative Science Quarterly*** 35, no.1 (March 1990): 10.

[16] Freeman and Soete, The Economics of Industrial Innovation, 148-149.

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Chinese Models of Technology and Innovation Development

In their pursuit of national and defense technology development, the Chinese authorities have put forward a three-step strategy that they label as "indigenous innovation". The stated goal is for technological self-sufficiency, but this is a long-term aspiration that will take decades. The near to medium term reality of the next decade or more is of continuing heavy reliance on foreign sources for technology and knowledge, although combined with increasing levels of domestic input. The MLP offers an explanation of the three parts of this indigenous innovation approach:

- **Original Innovation (*Yuanshi Chuangxin*** 原始创新): This refers to scientific discovery and technological invention carried out by Chinese research institutions that eventually are successfully developed and commercialized. The meaning of original innovation appears to have expanded in recent years to include an emphasis on breakthrough innovation. Chinese Academy of Sciences President Bai Chunli pointed out in a 2013 article that China's priorities in the pursuit of original innovation in the basic sciences were in six areas: energy and natural resources, information and networking, advanced materials, manufacturing, agriculture, and health care.[17] Original innovation would correspond with the concept of radical innovation.
- **Integrated Innovation (*Jicheng Chuangxin* 集成创新):** This means the synthesis of related technologies and processes that facilitates the development of competitive products and industries. These technologies and processes can be both foreign and domestic. This concept appears to be based on the innovation experiences of Japanese companies such as Toyota and Sony that organized their research, development, design, production, marketing, and sales channels into an integrated process and which turned them into global innovation powerhouses. Integrated innovation has many of the same features as architectural process innovation.

[17] Bai Chunli, "Strive To Make Breakthroughs in Original Innovation", ***Jingji Ribao (Economic Daily)***, 15 January 2013. Bai discusses specific details of technologies being targeted in each of these areas. In energy and natural resources, a top priority is the development of reliable, clean and renewable nuclear energy. In information and networking, the emphasis is on broadband, wireless, intelligent networking, supercomputing, virtue reality, and cloud computing. For advanced materials and manufacturing, the focus is on environmentally friendly green products and processes. In agriculture, attention is being paid to evolutionary biodiversity, especially highly active antiretroviral therapy, and eco-agricultural seed breeding. In health care, key areas of work are in disease prevention, stem cell research, and regenerative medicine.

- **Re-Innovation (*Zai Chuangxin* 再创新)**: This model is based on the identification, acquisition, and absorption of foreign technologies and processes through a multi-stage sequence of introduction (*Yinjin* 引进*)*, digestion (*Xiaohua* 消化*)* , and assimilation (*Xishou* 吸收) that leads to re-innovated (*Zaichuangxin* 再创新) output. This can be concisely referred to as the IDAR (Introduce-Digest-Assimilate-Re-innovate) strategy and would be similar to the concept of creative adaptation.[18]

Of these three approaches, IDAR is the most important and relevant to China's current S&T needs. The IDAR technology absorption strategy is most clearly articulated in a supplementary document to the MLP that calls for encouraging the introduction of advanced foreign technology that can be digested and absorbed for re-innovation.[19] The document, titled the "Opinions to Encourage Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade" was issued by a group of eight powerful government economic, financial, and planning agencies that included the National Development and Reform Commission, Ministry of Finance, and Ministry of Commerce.

The central goal of the 'Opinions' is the building of a sophisticated advanced apparatus that brings in foreign technology transfers and allows for the effective absorption and re-innovation of products that China can effectively claim to be homegrown. A number of industrial sectors are highlighted that would benefit from this approach, including information communications technology, biotechnology, civilian aviation and aerospace, advanced materials, and machinery manufacturing.[20] Key initiatives that are emphasized include:

- Actively seeking bilateral and multilateral technical cooperation;

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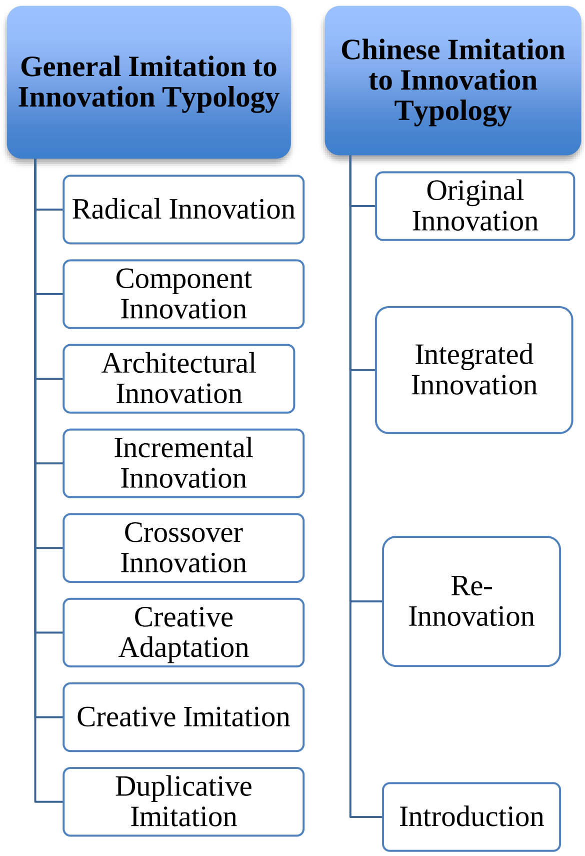
[18] A variant of the IDAR model is *Shanzhai* (山寨), which is a business model aimed at producing cheap products through imitation of foreign technology that is good enough for the lower end of the Chinese market.

[19] Ministry of Commerce, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, General Customs Administration, General Tax Administration, State Intellectual Property Office, and State Foreign Exchange Office, ***"Opinions to Encourage Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade",*** 14 July 2006, http://www.most.gov.cn/ztzl/gjzctx/ptzcyjxh/200802/t20080225_59303.htm

[20] For an example of how one industry implemented this strategy, see "Railway Ministry: Our Country's Railway is About How to Introduce, Absorb, and Re-Innovate", ***Xinhua News Agency***, 29 April 2007, http://news.xinhuanet.com/politics/2007-04/29/content_6043932.htm

- Improve and expand open source international information services that can be disseminated to local actors;
- Encourage and help firms to go abroad to gain access to foreign research and development knowledge;
- Attract more multinational firms to set up R&D institutes and facilities in China.



General Imitation to Innovation Typology vs. China's Official Imitation to Innovation Typology

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The Role of Foreign Technology and Know-How on China Defense Technology Development

China's defense science and technology industry has been heavily reliant on foreign sources for its science and technology development. In the 1950s, the Soviet Union provided extensive transfers of defense and civilian technologies and knowledge, which played a pivotal role in China's industrialization.[21] The abrupt cut-off in Sino-Soviet relations in 1960 along with China's continuing isolation from the West in the 1960s and much of the 1970s seriously retarded national and defense technological and industrial development.

While China invested heavily on foreign technology imports, its ability to absorb these technologies between the 1950s and 1990s was severely lacking. Long Guoqiang, a senior researcher in the Foreign Economic Relations Department of the State Council Development Research Center, has pointed out that, "China emphasizes the introduction of technology but does not pay attention to its absorption".[22] Applying this to the theoretical framework, China did have good potential absorptive capacity but did not adequately develop its realized absorptive capacity. Defense science and technology leaders were keenly aware of the importance of absorption, but making this happen in an industrial structure geared towards low-level forms of imitation would not be easy. Gen. Zhang Aiping, who was one of the principal architects in the building of China's armaments apparatus between the 1950s and 1980s, called the "digestion and absorption" of imported technologies a "force multiplier".[23]

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[21] See Baichun Zhang, Jiuchun Zhang, and Fang Yao, "Technology Transfer from the Soviet Union to the People's Republic of China 1949 –1966", ***Comparative Technology Transfer and Society,*** Vol. 4, No. 2, August 2006, and Shen Xiaoyong, "Viewing China's Defense Industrial Development From the Perspective of Technology Introduction, 1949-60", [技术引进视角角下我国国防工工业发展研究, 1949-1960)], ***军事历史研究 [Military Historical Research],*** January 2012.

[22] "From Technology Introduction to Indigenous Innovation, Era Shift Urgently Demands New Development Model: What Foundations Must Be Laid for Independent Innovation Against Backdrop of Globalization -- Interview With State Council Development Research Center Foreign Economic Relations Department Deputy Director Long Guoqiang", ***Guoji Shangbao***, 5 March 2007.

[23] "Zhang Aiping's Thinking on Defense Science and Technology", ***Junshi Lishi Yanjiu*** [Military History Research], No.3, 2007, p55

The Chinese authorities only became serious in developing a credible absorption model from the end of the 1990s. Tsinghua political economist Hu Angang argues that it was not until after China's accession to the World Trade Organization in 2001 that this "greatly increased its ability to import foreign technology, fully utilizing its ability to re-innovate technology (including imported innovations, copied innovations, and integrated innovations)." [24] Chinese expenditures on the acquisition of foreign technology and in-house assimilation of technology shows state support for absorption grow gradually from the 1990s, although it only picks up pace from the early to mid-2000s as science and technology development gains high-level attention.

[24] Hu Angang, "The Path of Indigenous Innovation with Chinese Characteristics", ***Kexue Shibao***, 6 April 2014.

From Introduction to IDAR: The Case Study of the Spey Mk 202 Jet Engine

The enormous struggle that the Chinese defense industry has had in successfully mastering absorption can be vividly illustrated with the case study of the Rolls Royce Spey Mk 202 jet engine. The Chinese aero-engine sector spent nearly 3 decades to acquire the engine and 're-innovate' it into a Chinese branded product known as the Qinling II, which is significantly longer than the time it takes for Western and Russian companies to develop a new generation of military aero-engines.[25]

The Spey Mk 202 is a second-generation engine that was developed in the 1960s and powered the British version of the F-4 Phantom. When the Xian Aero-Engine Co. (XAE) first approached Rolls Royce to purchase and locally assemble the engine in the early 1970s, the Spey was already around two decades old and coming towards the end of its service life.[26] The impending obsolescence of the Spey though did not concern the Chinese side, which was eager to seize the opportunity to acquire an engine technology that was a generation more advanced than what its domestic industry was able to produce.

This first effort by XAE to acquire the Spey and its production technology showed why the Chinese defense industry did not fully understand the critical steps required for successful absorption, especially the need for both potential and realized absorptive capacity. In the deal that was signed in 1975, XAE agreed to license produce the Spey. As part of this process, XAE acquired sophisticated lathes, milling and broaching machines, and new testing equipment. It also sent 400 engineer and workers to the UK for short-term training.[27] The Chinese side

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[25] Li Ming & Mao Jingli, ***Zhuanbei Caigou Lilun Yu Shijian*** [The Theory and Practice of Equipment Acquisition] (Beijing: Guofang Gongye Chubanshe [National Defense Industry Press], 2003), p291; and Zhou Rixin (Chief Ed), ***Zhongguo Hangkong Gongye Sishi Nian*** [40 Years of the Chinese Aviation Industry] (Beijing: Hangkong Gongye Chubanshe [Aviation Industry Press], 1991), pp241-243.
[26] Peter Pugh, ***The Magic of a Name: The Rolls-Royce Story, Part 2: The Power Behind the Jets*** (London; Icon Books, 2000),
[27] "Xian Aero Engine Company Forced to Change Due to Lack of Business From Home Market", ***Flight International***, 15 January 1992, p29.

only agreed to assemble a small batch of 10 engines, of which four would be produced from parts made by XAE and the remaining examples would be built from kits supplied by Rolls Royce. The primary aim of this agreement was to enable XAE to acquire the production capabilities to reverse engineer and manufacture the engines on their own.

While Chinese scientists and engineers were able to gain valuable insights into the Spey's technology that could be used for their own indigenous R&D efforts, the tiny production run meant that little was learnt on the actual process involved in building the engine. The Chinese side were also reluctant to share much of what they were doing with the British side. Rolls Royce technical experts that were sent to Xian to provide assistance were not allowed access to the production facilities and were instead visited at the hotels where they were staying by Chinese counterparts and asked questions. Rolls Royce technical advisers on the project were baffled by the Chinese approach and they pointed out that the serial production of aircraft engines were crucial to successfully assimilating the knowledge required in mastering this technology.[28] The Chinese side though believed that the procurement of a few samples, which would be taken apart and examined in detail, would allow them to copy the engine.

Not surprising, the Chinese strategy was a major failure and XAE struggled to absorb the Spey technology without adequately investing in digestion and assimilation processes. The Chinese side approached Rolls Royce in 1980 and proposed a joint project to develop a new version of the Spey, but this was rejected by the British company because of the lack of commercial opportunities that would result from the upgrading of an obsolete design.

After another decade and a half of frustrating technological progress, the Chinese aviation authorities changed their approach in the second half of the 1990s and agreed to enter into a closer and more cooperative joint relationship with Rolls Royce with the focus on both technology process and product development. Coincidentally, this change in strategy occurred around the same

[28] Li and Mao, Op. cit., p298.

time that the Chinese authorities began to shift from their failed introduction strategy and develop the more robust IDAR approach. A joint venture aero engine factory was established in 1996 between XAE and Rolls Royce to produce engine components such as nozzle guide vanes and low-pressure turbine blades for civilian aircraft.[29] In 2001, Rolls Royce sold another 90 reconditioned Spey engines and spare parts to China to equip the JH-7 navalized combat aircraft[30] and also reportedly agreed to allow this engine to be built under license.[31] Two years after this reported agreement, China announced the certification of the WS-9 Qinling II engine and it finally went into serial production in the late 2000s.[32]

The long-running Spey saga was a harsh lesson for the Chinese aircraft engine industry, but it appears to have made important adjustments to its technology importation strategy as a result. Since the late 1990s, China has been actively engaged in procuring third generation military jet engine technology and know-how from Russia. But instead of concentrating on reverse engineering activities, the focus has been on obtaining finished products for immediate operational utilization and at the same time pursuing negotiations to acquire technology transfers such as through license production and co-development projects. Since the beginning of this century, China has reportedly acquired large numbers of AL-31FN and Klimov RD-93 engines to equip its new models of fighter aircraft. In addition, the Russians agreed to build a facility that would allow the Chinese to repair and maintenance the AL-31 engines that also power its Su-27 and J-11 fighters.[33]

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[29] "Euro Hopes High as Air Engine Deal Takes Off", ***China Daily***, 21 May 1996.
[30] David Lague, "Buying Some Major Muscle", ***Far Eastern Economic Review***, 24 January 2002.
[31] "British Engine Sought for JH-7 Strike Fighter", ***Defense News***, 20 July 2001.
[32] "Xian Military Representative Office Supervises Making of Chinese Aero-Engine", ***Jiefangjun Bao***, 15 July 2008; and "Interview With PLA Aero-engine Expert on Qinling Engine, Others", ***Jiefangjun Bao***, 14 July 2010. "Appraisal of the Localization of the Qinling Aero-Engine", ***China Aviation News***, 22 July 2003; "Building a Powerful 'Chinese Heart': Interview With Ye Xinnong, Aeroengine Expert and Chief Representative of a Navy Military Representative Office," ***Jiefangjun Bao***, 14 July 2010; Lan Xin (Ed), ***Development of the Contemporary Chinese Aviation Industry Part 2: Transport Aircraft, Helicopters, Engines, and Avionics (中国当代航空工业发展概况一2)*** (Beijing, Audio-Visual Press [学苑音像出版社], 2004), pp71-74; and Phillip C. Saunders and Joshua K. Wiseman, ***Buy, Build, or Steal: China's Quest for Advanced Military Aviation Technologies,*** (Washington D.C., National Defense University, 2011).
[33] ***Kommersant***, 11 July 2005, and "China Jet Deal May Pique New Delhi", ***Moscow Times***, 20 April 2005.

Perhaps the principal reason behind the failure of the engine industry's catch-up efforts was the lack of high-level leadership and institutional support. During the 1960s and 1970s, the overriding priority for the country's political, military and defense industrial authorities was the development of strategic nuclear, space and missile capabilities and this led to the diversion of resources from competing sectors such as the aviation industry. In addition, internal political upheavals resulting from the Cultural Revolution led to serious disruptions in the industry's development.

This absence of institutional support for the aviation and engine industries continued into the reform era, especially during the 1980s and the first half of the 1990s with the sharp downturn in military budgets and the downsizing of the military and defense industrial establishments. During this period, the government bureaucracy responsible for overseeing the aviation industry underwent a series of extensive restructurings that eventually led to its transformation into a state corporation. These reforms led to the gradual but steady decline erosion in the aviation industry's access and influence within key political and defense industrial decision-making circles.

Another reason for the aero-engine industry's dismal absorption record was the lack of funding available to support assimilation activities. Investment funding for aero-engine research and development before the 21st Century was a fraction of what was spent by advanced aero-engine powers. One typical case was the WP-6 turbojet, which was the principal jet engine used by the PLA Air Force's J-6 and Q-5 fighter aircraft from the 1960s to the 1980s. Total investment outlays over a 20-year period for the development of the engine was Rmb 150 million, which was just 5 percent for a comparable Western program.[34]

Excessive Chinese dependence on Soviet technology and knowledge transfers offers another explanation for the poor absorption record of the aero-

[34] Han Xinwei, Chen Liangyou & Wu Hao, "Jiakuai Zhongguo Hangkong Fadongji Fazhan De Duice Yanjiu" [Countermeasures in Speeding Up the Development of Chinese Aero-Engine Development], ***Beijing Hangkong Hangtian Daxue Xuebao (Shehui Kexue Bao)*** [Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition)], Vol. 16, No.4, December 2003, p40.

engine industry. In the 1950s, the Soviets provided the technological knowhow through design blueprints and manufacturing capabilities to China to license produce early second-generation jet engine models. The Chinese aero-engine industry though lacked a sufficiently large pool of well-trained and experienced scientists and engineers who were able to assimilate these transfers, although they were sending sizeable numbers of personnel to the Soviet Union and Eastern Europe for advanced training. The abrupt rupture in Sino-Soviet relations in 1960 meant that these long-term training efforts were halted in mid-stream.

Consequently, the aero-engine industry, as well as the rest of the aviation industry, struggled to absorb the treasure trove of Soviet technology transfers and could only succeed in making modest incremental modifications and upgrades.[35] The impact of this early breakdown in the building of a nascent absorptive capacity had long-term consequences. One article pointed out that the Chinese Academy of Engineering only had five aero-engine experts in 2010, most of whom were retired and passing from the scene.[36] The article noted that an advanced aero-engine industry needs the skills of experts across several dozen specialized fields.

[35] See Duan Zihou (Chief Ed), ***Dangdai Zhongguo De Hangkong Gongye*** [The Contemporary Chinese Aviation Industry] (Beijing: Zhongguo Shehui Kexue Chubanshe [China Academy of Social Sciences Press], 1988, pp. 229-294.

[36] Liu Yun: "The Talented Personnel Factor in China's Long-Term Lag in Aircraft Engine Technology", ***Conmilit*** (Xiandai Junshi), 5 November 2010, p. 80.

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The Different Stages of the IDAR Model and Case Studies of Technology Absorption and Innovation in the Defense Domains

The IDAR concept has only been implemented in practice since the 1990s when various portions of the civilian and defense research and development apparatuses and industrial economy began to pay serious attention and devote resources to digestion and absorption.[37] Chart 1 provides an overview of the types of entities that can be found in the three stages of the IDAR process (introduction-digestion-absorption) as well as the re-innovated output that eventually emerges.

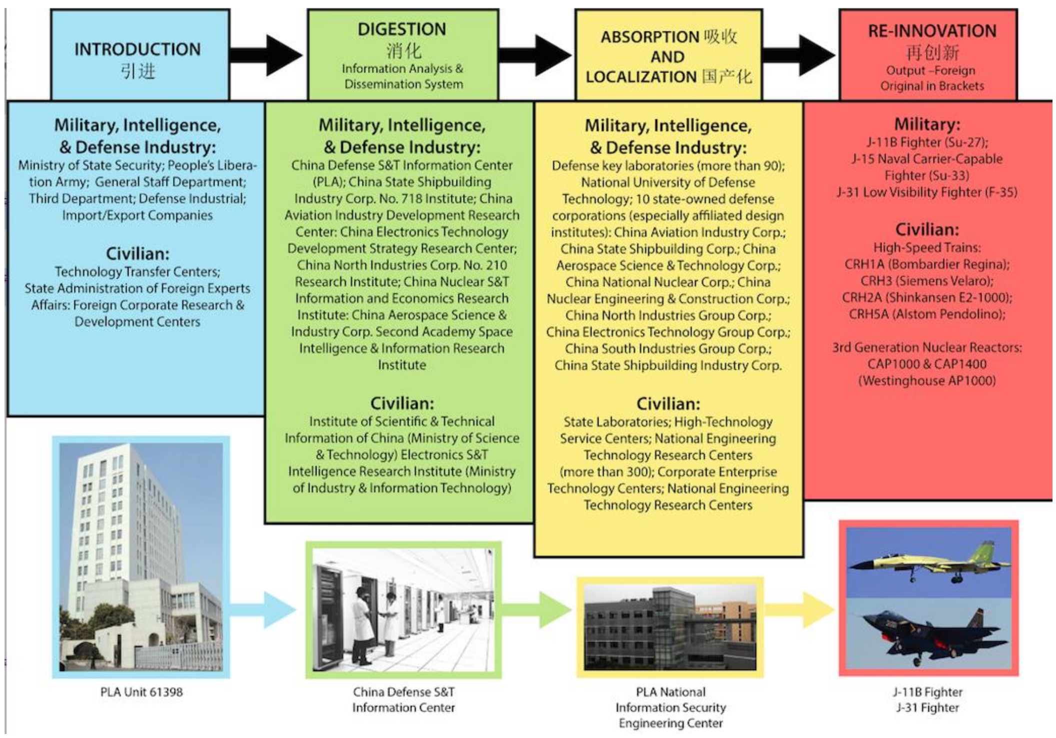

Chart 1: Key Chinese Civilian and Defense Organizations Within its IDAR System

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[37] For Chinese writings on the IDAR strategy, see Qiao Weiguo and Chen Fang, "Research on the Policy System and Implementation of Technology Importation, Absorption, and Re-Innovation" [引进消化吸收再创新的政策体系与

实施问题研究], ***Science and Technology for Development [科技促进发展]***, May 2010; and Li Nong, Qian Li, and Chong Xinong, "A Discussion of China's Technology Introduction and Indigenous Innovation Policy", [试论技术引进与我国自主创新发展战略现代财经], ***Modern Finance and Economics [现代财经]***, Vol. 27, No.12, December 2007, pp67-70.

1. Introduction

Gaining access to external knowledge is vital for the Chinese national and defense innovation systems to compensate for the gaps and inadequacies in their research and development bases and in order to meet ambitious development targets. There are a multitude of acquisition and technology transfer mechanisms and channels:

- Technology and equipment imports;
- Foreign direct investment and direct (explicit technology transfer agreements) and indirect (transfer of governance and other types of less tangible soft skill sets) spillover effects[38];
- Espionage through traditional industrial and information era cyber operations;
- Open source information collection and analysis;
- Establishment of foreign R&D centers;
- Human capital transfers and exchanges.

The most important of these channels for the Chinese defense innovation system are arms and defense technology related imports, espionage, and open source information collection and analysis. China is one of the world's largest arms importers and exporters. The Stockholm International Peace Research Institute estimates that China was the world's biggest arms importer between 2003 and 2007 with a global share of 12 percent and ranked second between 2008 and 2012 with a 6 percent share.[39]

The Chinese defense establishment has a large and well-developed joint civilian-military bureaucracy to manage this arms trade. On the military side, the PLA General Armament Department is the principal responsible agency involved

[38] This is the standard approach to civilian commercial technology transfers. For useful studies examining China and international technology transfer, see Giuditta De Prato and Daniel Nepelski, ***International Technology Transfer Between China and the Rest of the World*** (Seville; European Commission Joint Research Centre Institute for Prospective Technological Studies; Working Paper, 2013); John Van Reenen and Linda Yueh, "Why Has China Grown so Fast? The Role of International Technology Transfer", 2012; and Albert G.Z. Hu, Gary H. Jefferson, and Qian Jinchang "R&D and technology transfer: Firm-level Evidence from Chinese Industry," ***The Review of Economics and Statistics***, Vol. 87, No.4, 2005, 780-86. For a dated perspective on civilian and dual-commercial technology transfers in the 1990s, see Bureau of Export Administration, ***US Commercial Technology Transfers to People's Republic of China*** (Washington D.C., U.S. Commerce Department, 1999).

[39] http://www.sipri.org/research/armaments/transfers/measuring/recent-trends-in-arms-transfers

in the process, which has a military aid and trade bureau (军援军贸局) under its international cooperation department in charge of this portfolio. On the government side, the State Administration for Science, Technology, and Industry for National Defense (SASTIND) is the chief agency in charge through its military trade and foreign affairs department (军贸与外事司). Other government agencies that are involved include the Ministry of Industry and Information Technology (MIIT), State-Owned Assets Supervision and Administration Commission (SASAC), and the Ministry of Commerce. Commercially, there are around half a dozen specialized trading firms that are responsible for the import-export activities of the ten major state-owned defense corporations. The PLA relies on China Poly Group for its arms trade activities, especially arms imports from Russia.

In the face of long-term international restrictions on defense-related technology transfers, two of the primary mechanisms that the Chinese defense S&T system employs to mitigate these limitations are open source information collection and espionage activities. For open source information collection, China has built a substantial infrastructure that dates back to the 1950s and initially was created to support the country's construction of its strategic nuclear weapons and ballistic missile capabilities. Information collection is an integral element of the information analysis and dissemination (IAD) system, which will be assessed in the next section on assimilation.

Espionage also plays an important and growing role in China's defense acquisition efforts, although its value is difficult to gauge because of the lack of transparency. This comes in two forms: industrial espionage and computer network exploitation (CNE) or cyber espionage. Traditional industrial espionage has been the bread and butter of China's spying efforts since the founding of the Communist republic, but its impact on improving the Chinese defense S&T system appears to have been limited and episodic until the beginning of the 1990s because of the country's economic and technological isolation from the global defense economy.

An important turning point in China's industrial espionage efforts took place in the early 1990s with the collapse of the Soviet Union. This allowed China to take advantage of the economic chaos in Russia and former Soviet republics and gain access to their defense industrial facilities and scientific and engineering personnel. Hundreds of Russian defense scientists and engineers were recruited and brought over to China to provide expert advice, especially during the 1990s.[40] There has also been a proliferation of cases that show intensive Chinese intelligence-gathering activities taking place in the former Soviet Union. For example, the Russian chief executive of a rocket and missile company was imprisoned for illegally providing missile design information to China Precision Machinery Import-Export Corporation in 2007.[41] In another case also involving missile technology, two Russian academics from St. Petersburg's Baltic State Technological University were jailed in 2012 for selling classified information on the Bulava, Russia's latest generation intercontinental ballistic missile, to representatives of "Chinese military intelligence."[42]

A key role for defense S&T organizations is to provide technical targeting requirements to guide the work of collection units. Little information is known about how this targeting process works though, but the notoriously hierarchical and compartmentalized nature of the Chinese defense establishment would suggest that targeting requests by S&T organizations go up through their respective chains of command. Entities affiliated with the defense industry would report to the State Administration for Science, Technology, and Industry for National Defense (SASTIND), while PLA units would go through their own departments and service arms. Requirements by military units belonging to the armaments system, for example, will go up through the General Armament Department (GAD) hierarchy.

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[40] Interview with senior Russian Defense Ministry official, Moscow, April 1993 and reported in Tai Ming Cheung, "China's Buying Spree", ***Far Eastern Economic Review***, 8 July 1993. See also Tai Ming Cheung, "Ties of Convenience: Sino-Russian Military Relations in the 1990s", in Richard H. Yang (Ed), ***China's Military: The PLA in 1992/1993*** (Chinese Council of Advanced Policy Studies, Taipei, ROC), Boulder, Colorado, Westview Press, 1993.
[41] "Reshetin Sentenced to 11.5 years for Passing Technology to China", ***RIA-Novosti News Agency***, 3 December 2007.
[42] "Russia Professors Found Guilty Of Spying For China", ***Associated Press***, 20 June 2012.

For cyber espionage, military targeting requests eventually make their way to the PLA's General Staff Department's Third Department that is in charge of carrying out computer network exploitation operations.[43]

The effective management of these coordination and transmission channels is crucial to the performance of the acquisition process. Entities that are likely to play influential roles in providing targeting requirements include the Science and Technology Committees that belong to the GAD, SASTIND, each of the ten major defense industrial corporations, and S&T research organizations.[44]

2. Digestion

In the digestion of foreign technology and knowledge, a key mechanism that China has cultivated since the formative years in the development of its S&T research and development system in the 1950s has been a S&T information analysis and dissemination (IAD) apparatus.[45] A key rationale for the historical development of the IAD system was to provide information on global S&T developments to civilian and military S&T and academic organizations that were largely isolated from the outside world during the regime of Mao Zedong between the 1950s and 1970s. The output of this system consisted of the acquisition, collation, and translation of foreign S&T literature but also of specific technical information that was of direct utility to research and development organizations, especially for nuclear, space, and computational outfits.[46]

A number of major IAD entities were established within the S&T system, including the Institute of Scientific and Technical Information of China, which belonged to the State Science and Technology Commission (now the Ministry of

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[43] See Mark A. Stokes and L.C. Russell Hsiao, ***Countering Chinese Cyber Operations: Opportunities and Challenges for U.S. Interests*** (Washington D.C.; Project 2049, October 2012), http://project2049.net/documents/countering_chinese_cyber_operations_stokes_hsiao.pdf

[44] On the role of the GAD S&T Committee, see Eric Hagt, "The Science and Technology Committee: PLA-Industry Relations and Implications for Defense Innovation", in Tai Ming Cheung (Ed), ***Forging China's Military Might: A New Framework for Assessing Innovation*** (Baltimore, MD; John Hopkins University Press, 2014).

[45] See William C. Hannas, James Mulvenon, & Anna B. Puglisi, ***Chinese Industrial Espionage: Technology Acquisition and Military Modernization*** (London; Routledge, 2013), Chapter 2.

[46] Ibid, 20-21.

Science and Technology), and the Electronics Science and Technology Intelligence Research Institute that is presently affiliated with the Ministry of Industry and Information Technology.

The IAD system consists of around 400 analysis & diffusion centers with around 50,000 personnel, according to a 2006 assessment.[47] However, only around 35 belong to central government agencies and the rest are affiliated with provincial or lower level institutions.[48]

The vast majority of the external information that IAD organizations analyze comes from open sources such as media, online, and academic outlets.[49] The classified intelligence collected by PLA intelligence agencies are likely to be only available for the military component of the IAD system, which is centralized under the China Defense Science and Technology Information Center (CDSTIC) that is affiliated with the GAD. CDSTIC has grown rapidly over the past few decades, especially since the end of the 1990s, to cope with intensive demand for its S&T information and analysis services from the defense innovation system, military organizations, and the country's leadership.[50]

Concerted efforts have been made to improve the ability of the IAD system to assimilate and disseminate information in a timely and organized fashion. This includes the development of Internet-based and closed intranet S&T databases and information retrieval networks. CDSTIC, for example, operates an engineering technology information network, an all-army equipment S&T information network, a GAD-specific S&T intelligence network, and an online digital library.[51]

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[47] Xu Guanghua, "The Development of the S&T Information Industry in the Building of an Innovation Country", Speech at the 50th Anniversary of the Institute of Scientific and Technical Information of China, 16 October 2006.
[48] Hannas, et al, 22.
[49] One study suggests that 80 percent or more of S&T technical information requirements can be obtained from open source publications, while the remainder needs to be collected from 'special means'. Huo Zhongwen and Wang Zongxiao, ***Sources and Techniques of Obtaining National Defense Science and Technology Intelligence*** (Beijing; Science and Technology Literature Press, 1991), 84-85.
[50] "Science and Technology Vanguard, Think Tank for Decision-Making", ***Zhongguo Jungong Bao***, 17 November 2012.
[51] Ibid.

Another important aspect of digestion is learning and the Chinese national and defense S&T systems have built up an extensive apparatus of research universities, vocational colleges, laboratories, and research institutes to study and improve upon the acquired foreign technology and knowledge as well as to educate and train new generations of scientists and engineers for the country's innovation system. While the country's higher educational system is able to produce sufficient quantities of science and engineering graduates to satisfy demand from both the civilian and defense sectors, the quality of this talent pool is mixed.

The number of science and engineering (S&E) graduates from Chinese higher education institutions has surged since the late 1990s. In 1998, there were around 250,000 S&E first degree graduates, but this increased by more than 400 percent by 2010 to 1.1 million. By comparison, the U.S. produced around 280,000 S&E graduates in 2010.[52] Perhaps a better gauge of advanced educational quality that contributes to innovative capacity is the number of awards for doctoral degrees. Of the estimated 200,000 doctoral degrees that were issued worldwide in 2010, China accounted for 31,000, slightly behind the U.S. output of 33,000, although around 10 percent of the U.S. awardees were Chinese nationals. By comparison, China issued 1,900 doctorates in 1993.[53]

3. Absorption

Absorption is the third step of the IDAR process and this is the engineering stage in which the goal is to transform the acquired and digested knowledge and technology into output. This process is carried out through an assortment of approaches that include collaborative international joint ventures as well as through illicit transfers and reverse engineering, both authorized and unauthorized.

The Chinese authorities are investing heavily in building up an extensive technology and engineering eco-system to support efforts to combine digested

[52] National Science Board, ***Science and Engineering Indicators 2014***, (Arlington, VA: National Science Foundation, February), 2-38 to 2-39.
[53] ***Science and Engineering Indicators 2014***, 2-41.

foreign and local technologies. This includes the establishment of an extensive array of entities such as national engineering research centers, enterprise-based technology centers, state key laboratories, national technology transfer centers, high-technology service centers, and the recruitment of foreign technical experts through organizations such as the State Administration of Foreign Experts Affairs. National engineering research centers are one of the most important types of institutions designated by the Chinese government transforming the acquired and digested external technology into actual output. There were nearly 300 of these research centers in operation in 2013 and some of their key goals are:[54]

- To promote the transfer of advanced technologies and manufacturing processes for large-scale industrial production.
- Enhancing innovation ability by digesting and assimilating technologies introduced from abroad and re-creating new technologies through international cooperation and exchanges.

4. Re-Innovation and the Case Study of the Su-27 Fighter Aircraft

One of the first cases of the successful implementation of the IDAR strategy that paved the way for its adoption in the rest of the defense industry is the 're-innovation' of the Soviet Su-27 fighter aircraft into the Shenyang J-11B between the late 1990s and early 2000s. China had signed an agreement in 1995 for the license assembly and eventual manufacturing of the aircraft by Shenyang Aircraft Corp (SAC), one of the country's most advanced military aviation enterprises. A first production run of around 100 aircraft took place between the late 1990s and mid-2000s. Chinese engineers initially struggled to fully master the advanced manufacturing and industrial management methods needed to produce an aircraft that was a generational leap in technology. SAC was eventually able to absorb the processes and lift output to its maximum rate by the early 2000s.

As the two sides negotiated for another production round in the early 2000s, the Chinese were discovered to have been secretly reverse engineering the

[54] National Development and Reform Commission, 'Administrative Measures on National Engineering Research Centers', National Development and Reform Commission website, 5 March 2007.

aircraft, which they called the J11B.[55] This led to a major rupture in the two countries' defense S&T cooperation as Russia demanded that China halt such intellectual property rights infringements and guarantee not to further engage in these practices.[56]

China, however, pushed back and claimed that the J11B was a new aircraft with significantly improved avionics, the use of composite materials, and more advanced weapons systems. As the dispute continued into the late 2000s, China was found to have cloned another Sukhoi fighter, the Su-33, which was an improved naval carrier version of the Su-27 into the J-15. This project was not as big an irritant in China-Russia relations though because China had acquired a prototype of the aircraft from Ukraine in the early 2000s. In addition, the Su-30 also appears to have been re-innovated into the J-16. Beijing and Moscow eventually settled their differences in the early 2010s, which allowed for the resumption of negotiations for major weapons packages.

This access to former Soviet defense technology may have helped select portions of the Chinese defense industry to advance by at least one or more generations. The most significant contributions have been in fighter aircraft programs, air-to-air missiles, radars, fire-control systems, aircraft carrier and other naval systems, and manned space.

[55] "China's Imitation of Su-27SK and Its Impact", ***Kanwa Asian Defense Review***, May 2008.
[56] "China 'Cloning' Russian Weapons Despite Intellectual Property Agreement", ***Nezavisimoye Voyennoye Obozreniye***, 3 December 2010.

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Case Study of U.S. Technology Transfer to China's Aerospace Industry Through the Boeing 787

While Russian technology transfers have had a profound impact on the development of China's military aviation sector, Western technology transfers have been largely limited to China's commercial aviation industry. There has been significant long-term cooperation between the Chinese civilian airliner industry with the world's two leading Western commercial aircraft builders, the European consortium Airbus and Boeing Corp. of the U.S.

After several decades of supporting the production of Boeing's commercial jets, China saw the flight of its first passenger jet, the Commercial Aircraft Corporation of China (COMAC) C919, in May 2017. The C919 is a single-aisle aircraft that seats between 158-174 passengers. Although China clearly has ambitions to compete with Airbus and Boeing, it recognizes that there is still a long road ahead. The technologies used in the C919 development are still 10 to 15 years behind the newest versions of comparable aircraft, the Airbus 320 and Boeing 737. Nevertheless, COMAC has stated that it intends to take a fifth of the global narrow-body market by 2035.

This case study examines China's role in the production of the Boeing 787 (B787), the technology transfer that was involved, the specific methods of technology transfer (offset agreements and joint ventures), and the impact of technology transfer on the development and production of the C919 and China's industrial base.

Boeing 787

The B787 began its life in early 2003 with the designation B7E7. Boeing said this designation signaled its commitment to develop a new aircraft with major innovations in a number of areas, all beginning with the letter "E." These included "efficiency, economics, environmental performance, exceptional comfort and convenience, and e-enabled systems".[57] The B787 was designed to be a more fuel-efficient replacement of two existing Boeing aircrafts—the 757, which is no longer in production, and the 767. The aircraft's chief competitors include the Airbus A330-200 and A350.[58]

The B787 was delivered in three variants, the B787-8 (which can carry 210 to 250 passengers on routes of 7,650 to 8,200 nautical miles) the B787-9 (which can carry 250 to 290 passengers on routes of 8,000 to 8,500 nautical miles), and the B787-10 (which can carry 300 to 330 passengers on routes of 7,000 nautical miles). The B787 also achieved its goal of efficiency, burning 20% less fuel than other similar aircraft, while flying at speeds comparable to its predecessors. In late 2011, it set the record for the fastest around-the-world trip for an aircraft in its weight class, averaging 470 knots (541 mph. The construction of the B787 relied significantly on the use of composite materials. In fact, the aircraft is 50 percent composite by weight with the majority of the primary structure, including the fuselage, made of composite materials. The use of these materials allows for a lighter structure and less expensive maintenance.

The technological advancements of the B787 have come with a substantial price tag. As of June 2017, the Dreamliner has incurred a nearly $30 billion deficit from deferred production costs generated by the first few hundred B787s that were built.[59] The complex, global supply chain made Boeing susceptible to delays, which were further complicated by technical difficulties with composite materials and electric systems. These delays have resulted in substantial costs that have limited the overall profits of each sale. In response, Boeing is actively trying to reduce its production costs and timeline in order to overcome the deficit.[60] As of

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[57] Boeing Corp., ***History of 787 Commercial Transport***, http://www.boeing.com/history/products/787.page Accessed 7 August 2017.

[58] "The New Technology Boeing 787 Dreamliner, Which Makes Extensive Use of Composite Materials, Promises to Revolutionize Commercial Air Travel", ***Aviation Week & Space Technology,*** Vol. 162, Issue 11, 14 March 2005.

[59] Alwyn Scott, "Boeing barrels ahead on 787 and 777 cost reductions", ***Reuters,*** 8 June 2017 http://www.reuters.com/article/us-boeing-airshow-production-idUSKBN18Z131

[60] Chris Bryant, "Boeing's $32 Billion Accounting Question", ***Chicago Business***, 14 April 2016 http://www.chicagobusiness.com/article/20160414/NEWS05/160419886/boeings-32-billion-accounting-question

July 31, 2017, a total of 578 B787s have been delivered; the remaining 700 orders are still unfilled.[61]

Technology Transfer and China

As outlined in China's 13th Five-Year Plan, China aims to implement policies that will build domestic capacity while "slowly closing market opportunities for U.S. companies in the United States and in third country markets in important high-tech sectors" such as biopharmaceuticals, robotics, and aviation.[62] The development of its own aerospace industry and technological capabilities has been a central objective of the Chinese government for some time; its ongoing relationship with Boeing, extending back more than 30 years, has played a part in achieving this goal.

Every one of Boeing's commercial aircraft incorporates components or modules manufactured in China.[63] Roughly, one-third of Boeing's world fleet has major parts and assemblies built in China, with the country having participated in the B787, B777, B747 and B737 projects. For example, China had built the trailing edge wing ribs, vertical fins, horizontal stabilizers, spoilers and inboard flaps for the 747-8 and the wing panels and doors on the Next-Generation 737.[64]

Since 1993, Boeing has invested in the training and professional development of Chinese aviation professionals by offering free training in pilot, maintenance, flight operations, and management techniques. In November 2012, it launched The Boeing Academy-China to provide more enhanced, integrated training initiatives in China.[65] Later in 2014, Boeing and the state-owned aerospace and defense company, the Aviation Industry Corporation of China

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[61] Boeing Corp., "Boeing 787 Highlights $600 Million in Contracts with Chinese Suppliers", http://boeing.mediaroom.com/2005-06-02-Boeing-787-Highlights-600-Million-in-Contracts-with-Chinese-Suppliers Accessed 22 August 2017.
[62] Katherine Koleski, ***The 13th Five-Year Plan,*** U.S.-China Economic and Security Review Commission, Staff Research Report, 14 February 2017.
[63] K Crane, J Luoto, Harold Warren, D. Yang, S.K. Berkowitz, and X. Wang, **The Effectiveness of China's Industrial Policies in Commercial Aviation Manufacturing** Rand Corp., 2014.
[64] Wang Yukui, ***Boeing in China Backgrounder***, 2015. www.boeing.com/resources/.../china/.../boeing-china-backgrounder-q32015_en.docx
[65] Ibid.

(AVIC) collaborated to establish a Manufacturing Innovation Center in one of the AVIC facilities that would provide training for AVIC employees on Boeing's production methods in an effort to improve the employees manufacturing and technological capabilities. In 2015, Boeing and AVIC signed an agreement to improve AVIC's manufacturing capabilities "by adding major component and assembly work packages, strengthening leadership, and developing AVIC's broad aviation infrastructure and business practices, including supply chain management".[66] Indeed, technology transfer is often the result of the intentional sharing of technology and processes.

Over the last few decades, China has made several attempts to break into the global aerospace industry as a commercial aircraft producer. In the 1980s, China built the Y-10, a civilian airliner that was based on the reverse engineering of the Boeing 707, and the Xi'an Aircraft Corporation developed the Y-7, a 60-seat turbo prop regional aircraft; both were deemed commercial failures and were plagued by safety concerns.[67] According to Crane, "the Chinese government moved to adopt "a strategy of first engaging in domestic production and assembly using foreign designs, then developing its own designs with foreign assistance, culminating in completely independent domestic development of a commercial aircraft without foreign assistance".[68]

Thus far, this strategy seems to be remarkably successful. AVIC has secured international sub-contracts and sub-system joint ventures, largely thanks to cheap labor and large sales prospects, becoming the sole suppliers of some items.[69] Specifically, China's extensive involvement in the manufacturing of B737

[66] Juliet Van Wagenen, "Boeing Inks Partnerships to Further China's Aviation Efforts", ***Avionics Today***, 24 September 2015, http://www.aviationtoday.com/2015/09/24/boeing-inks-partnerships-to-further-chinas-aviation-efforts/

[67] Andrea Goldstein, "The Political Economy of Industrial Policy in China: The Case of Aircraft Manufacturing", **Journal of Chinese Economic and Business Studies**, Vol.4, No.3, 2006, pp 259-273.

[68] Crane, op cit, pp xii.

[69] Goldstein, op cit.

parts and assembly of A320 for Airbus has improved its knowledge of the development and production single-aisle planes.[70]

China has used a variety of policy instruments to aid its aviation manufacturing industry. These instruments fall into the following six categories:

- **Setting up national champions:** In 2008, COMAC was created as a state owned manufacturer tasked to developing and producing commercial aircrafts manufactured in China
- **Launch aid:** Extensive financing is necessary whenever developing a new plane. COMAC has been generously supported by the Chinese government, including local governments, in the form of financial assistance, land for manufacturing plants, and subsidies to support the aircraft industry.
- **Encourage state-owned airlines to buy Chinese aircraft:** Chinese domestic airlines account for the majority of the aircraft orders for both the ARJ-21 and C919, the two aircrafts produced by China. The three largest airlines in China are state-owned and rely on state financial support. The Civil Aviation Administration can compel airlines to buy Chinese manufactured airplanes.
- **Use loans and politics to encourage foreign purchases of Chinese aircraft:** "The Chinese government has employed both the Chinese diplomatic corps and offers of loans in pursuit of sales of its commercial aircraft".[71] This strategy has had limited success.
- **Target orders to foreign manufacturers with assembly operations in China or who source from China:** Western companies that establish assembly operations can benefit from sales because offset agreements can factor into Chinese decisions on aircraft purchases.
- **Joint ventures between foreign suppliers and Chinese partners: "**The Chinese government sees procurement of components by foreign aircraft manufacturers as helpful for introducing modern management and production practices to Chinese partners".[72] Joint ventures can help spur technology transfer needed to further develop the Chinese industry.

Of the instruments described above, the latter two—offset agreements and joint ventures—have had the greatest impact on aerospace technology transfer to China. In simple terms, industrial offset agreements transfer technology and/or production from a U.S. company to another country in return for a sale. Offset

[70] Keith Bradsher, "China's New Jetliner, the Comac C919, Takes Flight for First Time", ***New York Times***, 5 May 2017 https://www.nytimes.com/2017/05/05/business/china-airplane-boeing-airbus.html
[71] Crane, op cit pp33.
[72] Ibid, p29.

agreements are common in industries with high per-unit selling prices and may also include benefits such as subcontracting or worker training.[73]

Through offset agreements, China has become a popular source of assembly labor, which has helped them build production competence in key areas shown in the table.[74] Table 1 shows the China's offset agreements, which predate the B787 program.

China aircraft offset programmes

Assembly/part	Programme	Source/Offset
Vertical fin & tail	Boeing 737	Boeing USA
Empennage	Boeing 757	Vought USA
Final assembly	MD-82	McDonnell USA
Nose & wing	A320	Airbus Europe
Final assembly	A320	Airbus Europe

Table 1. China Aircraft Offset Programs

Offset agreements facilitated the sale and production of the Boeing 787. Seventy percent of the components in the B787 are sourced from foreign suppliers.[75] A global supply network was built to allow Boeing to lower costs, speed up development and take advantage of the state-of-the-art technologies from commercial providers around the world. Many suppliers are full partners in the project, having invested their own money in the development and manufacturing of the B787's parts.[76] Boeing adopted the role of integrator/architect, with partners responsible for funding development, design and manufacturing, which enabled a real-time collaborative environment where partners were able to utilize each other's expertise to improve the quality of the product.[77] This type of approach

[73] A. MacPherson and D. Pritchard, "The International Decentralization of US Commercial Aircraft Production: Implications for US Employment and Trade", ***Futures,*** Vol. 35, No. 3, 2003, pp 221-238.
[74] Ibid.
[75] Keith Epstein Judith Crown, "Globalization Bites Boeing", ***Bloomberg Businessweek***, 24 March 2008.
[76] Benjamin Zhang, "Trump Just Used Boeing's New Global airliner to Attack Globalization", ***Business Insider,*** 17 February 2017 http://www.businessinsider.com/boeing-trump-administration-policies-effects-dreamliner-787-2017-2
[77] Aviation Week, 2005, op cit.

permits aircraft companies to “invest less capital into new launch programs” by “outsourcing the bulk of the development and production costs to risk-sharing partners”.[78] This strategy requires the infusion of tacit scientific and technical knowledge” to these partners.[79]

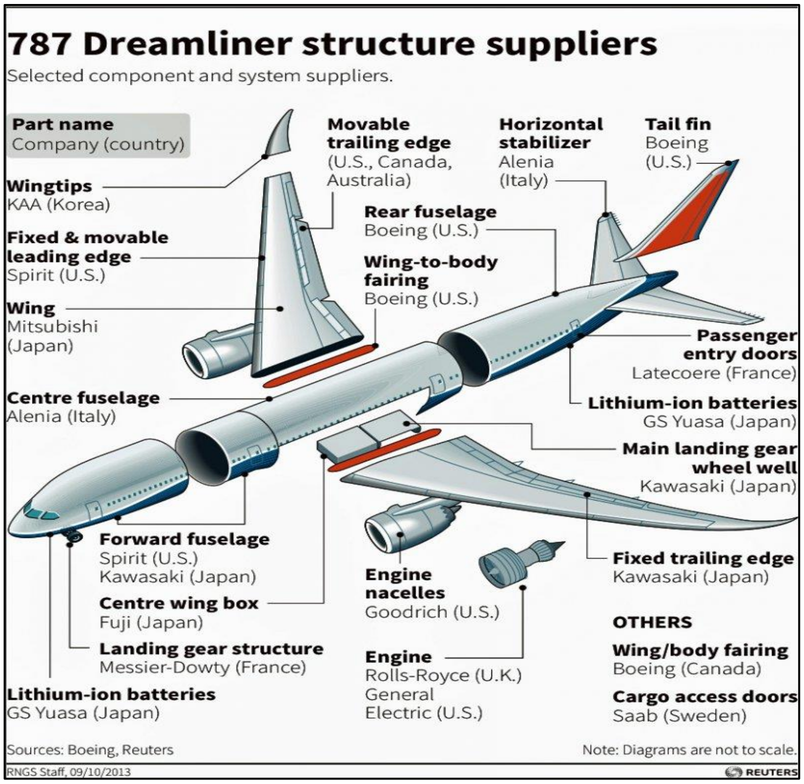

Figure 1. Boeing 787 International Suppliers. China supplies several structural parts, even though they are not highlighted

Although not highlighted in the figure above, China is the sole source provider of several 787 parts made of composite materials, including the rudder, fin, and fairings. As indicated previously, 787 production relied heavily on composite materials, with 50 percent of the aircraft by weight made from the aluminum replacements. By comparison, the B777 was only 12% composite. The

[78] D. Pritchard and A. MacPherson, “Strategic Destruction of the Western Commercial Aircraft Sector: Implications of Systems Integration and International Risk-Sharing Business Models”, ***The Aeronautical Journal***, Vol. 111, 2007, pp327-334.
[79] Ibid.

use of composites was pioneered by the U.S. military's B-2 program in 1989. Boeing built the primary structural components, including the outboard and aft-center sections of the aircraft's fuselage. The B-2 was 38 percent composite by weight. The advances made in composite technology during this period were later incorporated into Boeing's commercial aircraft designs.

The increase in composite use coincided with Boeing's investment in the Chinese composite industry. Boeing has invested in Boeing Tianjin Composite Co. Ltd (BTC), through a joint venture with AVIC, which is responsible for manufacturing composite structures for Boeing airplanes.[80] BTC has helped manufacture composite structures for the B747, B777, and B787. As a result of this partnership, China has had access to state-of-the-art facilities, equipment, technology, and manufacturing techniques. The vertical stabilizer and rudder of China's C919 are made of composite material and, overall, the C919 is 15 percent composite by weight—far less than the B787 but more than the B777. Offset agreements, it must be concluded, have served as a mechanism for technology transfer.

China's reliance on joint ventures to produce the C919 (pictured on the right) has accelerated the trend of technology transfer to the Chinese industrial base. COMAC requires that its tier one suppliers establish joint ventures with Chinese companies for in-country assembly of C919 components, thereby strengthening industry techniques and skills.

The figure below shows some of the major Western partners for the C919. By relying on multiple international partners and implementing joint venture agreements, China is able to leverage the supply chains used by Airbus and Boeing, making it easier for COMAC to avoid many of the technical challenges that

[80] Wang Yukui, op cit.

a country might experience when trying to build a commercial aircraft for the first time.[81]

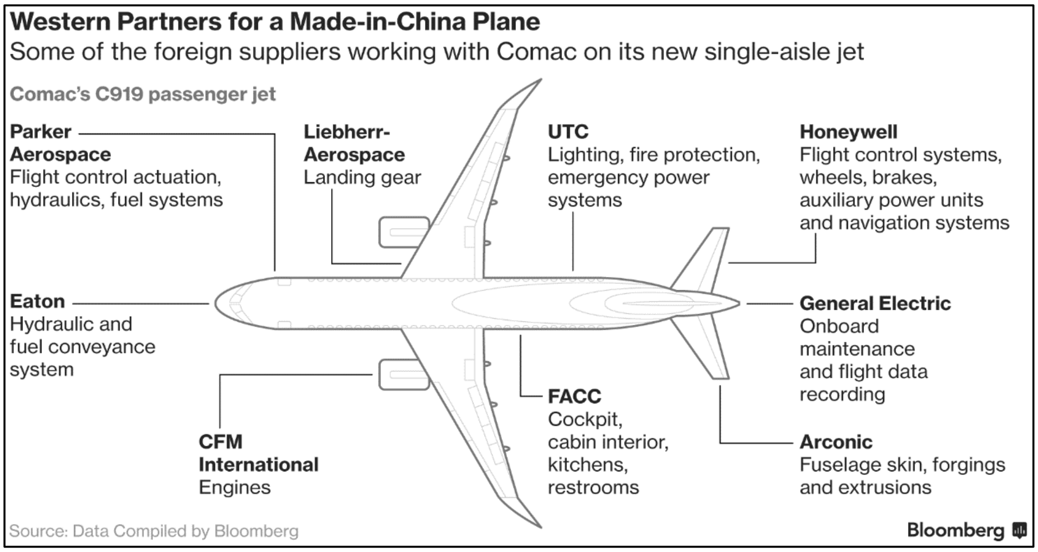

Figure 2. China's Joint Venture Partners for C919 development and production

In 2011, China acquired Western avionics technology through Aviage Systems, a 50/50 joint venture between AVIC and GE. GE Avionics, it should be noted, provided the common core avionics system for the 787.[82] Much of the avionics technology was initially developed by Smiths Aerospace, the firm that provided the core avionics processing unit for the Eurofighter, which was also adapted for use in the F-22. Smiths Aerospace was acquired by GE in 2007. Hence, much of the technology used in producing the avionics system for the C919 can be traced to advances made during B787 and Eurofighter development and production. The avionics system is not the only example of technologies shared by the B787 and the C919. The table below lists some of the common suppliers and products shared by the two aircraft.

[81] "China's New Plane will be Helped Aloft by U.S. Technology", ***Bloomberg***, 4 May 2017 https://www.bloomberg.com/news/articles/2017-05-04/china-s-first-jet-to-rival-boeing-is-helped-by-u-s-technology

[82] C. Ohlandt, L. Morris, J. Thompson, A. Chan, and A. Scobell, ***Chinese Investment in U.S. Aviation***, Rand Corp., 2017.

Supplier	Product
Moog Inc.	Electromechanical actuators
Safran Electrical & Power	Wire harnesses: electrical wiring systems
Arconic Fastening Systems	Fasteners
UTC Aerospace Systems, Interiors	Aircraft exterior lighting systems
Arconic Power and Propulsion (Arconic TITAL)	Metal & Alloy castings: aluminum and titanium investment castings
GarKenyon Aerospace & Defense	Hydraulic system valves
FACC AG	Wing spoilers
Monogram Systems	Waste water systems: water & waste systems
Parker Aerospace Hydraulic Systems	Hydraulic systems & equipment
Crane Aerospace & Electronics	Brake system components: brake control system
Michelin Aircraft Tire corporation	Tyres
Kidde Aersopace & Defense (UTC)	Fire fighting /detection systems
GE Aviation Systems	Flight management systems
Honeywell Aerospace	Inertial components & systems
UTC Aerospace Systems, Electric Systems	Electric power generation and distribution systems
Avio Aero	Engine parts
Ascent Automation: Flow Aerospace	Machining systems: CMC waterjet machines
Paragon D& E	Tooling
TechSAT gmbH	Test benches

Table 2: Common suppliers between the B787 and the C919

In conclusion, globalization has enabled the rapid transfer of high-level technologies through mechanisms including offset agreements and joint ventures. China’s long relationship with Boeing, in particular the country’s role in the production of the B787, and the associated technology transfer has accelerated the development of the first Chinese commercial aircraft. It is also interesting to note that many of the technologies incorporated into China's C919, including composite materials and avionics systems, were originally developed, in large part, by the U.S. Department of Defense, its industry partners, and its allies. From this perspective, the process of technology transfer that culminated in the production of the C919 began prior to the arrival of the B787.

To date, there are 730 orders for the C919, mostly Chinese airlines and leasing companies.[83] The Chinese commercial aircraft market is expected to be incredibly profitable with $400 billion in sales predicted over the next twenty years. The market is attractive to international suppliers who want to gain a position as a major supplier to Chinese producers.[84] While technology transfer has surely played a role in the development of the C919, China still has a long way to go before it is seen as a major player in the global aerospace industry. It lags far behind on key technologies related to carbon fiber and ceramics materials, core engine technology, engine blades and avionics, and the systems-integration skills which needed to ensure the viability of an advanced commercial aviation industry.[85] China's ability to disrupt the duopoly created by Boeing and Airbus remains to be seen; nevertheless, the production of the C919 indicates that China's strategy thus far has been effective.

[83] B. Goh, "China's COMAC Says Signs 130 orders for C919 Passenger Jet", ***Reuters***, 19 September 2017 https://www.reuters.com/article/us-china-aviation-comac/chinas-comac-says-signs-130-orders-for-c919-passenger-jet-idUSKCN1BU17V

[84] D Barboza, C. Drew, and S. Lohr, "G.E. to Share Jet Technology with China in New Joint Venture", ***New York Times***, 17 January 17 2011 http://www.nytimes.com/2011/01/18/business/global/18plane.html?mcubz=0

[85] Thomas Duesterberg, "Can the Chinese Create a Competitive Commercial Aviation Industry?", ***Aspen Journal of Ideas***, January/February 2015. http://aspen.us/journal/editions/januaryfebruary-2015/can-chinese-create-competitive-commercial-aviation-industry#page

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The Impact of Technology Absorption on the PLA's Force Projection Capabilities

The absorption and re-innovation of foreign technology and knowledge has been a powerful catalyst in advancing the overall modernization of China's armament capabilities since the late 1990s. This has allowed the PLA to close – and in some cases eliminate- the technological gap with regional and global competitors in an expanding number of areas. The biggest beneficiaries of the IDAR and other forms of technology importation strategies have been in the aviation, naval shipbuilding, and select precision strike missile sectors. Without these technological achievements that are being translated into operational capabilities, the PLA's shift to a more regionally assertive and maritime-oriented posture would have been little more than empty talk.

The military aviation sector has been especially reliant on the leveraging of foreign technology transfers to support its development.[86] A significant proportion of the country's combat aircraft development programs have depended on foreign, mostly Russian, technology inputs. These technology transfers come in several forms:

- **Reverse engineering:** The Chinese aviation industry has been able to reverse engineer complete platforms acquired through license assembly agreements (Su-27), off-the-shelf purchases (Su-30MK2), and opportunistic acquisition of prototypes (Su-33), which it then adapts and indigenizes with local sub-systems and components. A substantial proportion of the PLA Air Force's combat inventory consists of these re-innovated aircraft, such as the J-11B (Su-27), J-15 (Su-33), and J-16 (Su-30MK2).
- **Research and development assistance:** A number of Chinese 'indigenous' programs have received extensive levels of foreign assistance in their design and development, including co-design and co-development. Much of the original design of the J-10A fighter, for example, was from Israel and its Lavi fighter program. China and Russia are also reportedly close to signing an

[86] For useful background analysis, see Philip Saunders and Joshua Wiseman, ***Buy, Build, or Steal: China's Quest for Advanced Military Aviation Technologies*** (Washington D.C, National Defense University, Center for the Study of Chinese Military Affairs, 2011; and Cliff, Roger, Chad J. R. Ohlandt and David Yang, ***Ready for Takeoff: China's Advancing Aerospace Industry*** (Santa Monica, CA: RAND Corporation, 2011), http://www.rand.org/pubs/monographs/MG1100.

agreement on the co-design and development of a heavy-lift helicopter, of which Russia is in charge of aerodynamics design and China providing avionics systems.[87]

- **Critical components and sub-systems:** While the overall technological level of the Chinese aviation industry is steadily improving, there are pockets of backwardness in critical components and sub-systems. High-end turbofan jet engines stand out as the biggest weakness, which has made China dependent on Russian engines. Avionics, data fusion, radar systems, fire control systems, transmission gear, and advanced materials are other areas in which China looks to foreign sources for technology transfers.
- **Enabling technologies**: As the Chinese aviation industry becomes more sophisticated across all the stages of the research, development and acquisition process, it is sourcing foreign assistance for wind tunnels, computer-aided design and manufacturing software, and advanced production equipment such as multi-axis machine tools.

Foreign technology has also played an influential role in the improving technological performance of the naval shipbuilding industry. This was especially the case from the 1990s to the mid-2000s when there was extensive importation of Russian technology and knowhow. As Chinese shipbuilders absorbed these transfers, they have been able to substantially reduce their foreign reliance in the past decade. A 2015 U.S. Office of Naval Intelligence assessment of the equipment modernization of the PLA Navy's surface fleet noted that, "By the second decade of the 2000s, the PLA(N)'s surface production shifted to platforms using wholly Chinese designs and that were primarily equipped with Chinese weapons and sensors (though some engineering components and subsystems remain imported or license produced in country)."[88]

The ONI report noted that the last purchase of a foreign naval platform was the Sovremennyy-II guided missile destroyer in 2006 and since then the Chinese naval shipbuilding industry has been engaged in "much longer production runs of its domestically produced surface combatants and conventional submarines, suggesting greater satisfaction with recent designs. The Jiangkai-class (Type 054A) frigate series, Luyang-class (Type 052B/C/D) destroyer series, and the

[87] "China, Russia to Co-Develop Heavy-Lift Helicopter in 2016", ***China Daily***, 10 September 2015.
[88] U.S. Navy Office of Naval Intelligence, ***The PLA Navy: New Missions and Capabilities for the 21st Century*** (Washington D.C., Office of Naval Intelligence, April 2015, p14.

upcoming new cruiser (Type 055) class are considered to be modern and capable designs that are comparable in many respects to the most modern Western warships."

The transformation of the Admiral Kuznetsov class Varyag aircraft carrier into the Liaoning aircraft carrier between the late 2000s and the early 2010s offers a revealing case study of how the PLA Navy is moving from absorption to innovation in one of China's largest-ever defense industrial projects. In particular, the story of the Liaoning's refurbishment points to the strengths and weaknesses of different technological and engineering areas related to not only carrier development but to China's defense industrial modernization in general.

The remaking of the Liaoning initially began as an opportunistic acquisition of a partially constructed Russian aircraft carrier in the late 1990s, but the Chinese military authorities did not know what to do with the vessel as there was no decision as to whether the PLA Navy should have an aircraft carrier at the time. Consequently, it took several years before the Varyag was finally moved to China in 2002. It was not until 2004-5 that the military leadership finally gave approval for the establishment of an aircraft carrier program.

The rebuilding of the Varyag appears to be a case of engineering re-innovation and technological innovation. The major engineering challenges were to repair a badly rusted ship and to refurbish the ship's main engine, much of which appeared to have been retained although with some key components removed. According to a Japanese assessment of the Liaoning program quoting PLA Navy sources, the propulsion system was eventually rebuilt from this original engine.[89] The reliability of the propulsion system though is a serious concern, especially as a diesel generator failed during one of its early trial runs in 2012.[90] Besides the engine, all of the ship's other equipment, including wiring and pipes, had been

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[89] Bonji Ohara, "Doubts Dogging China's Aircraft Carriers", ***Sekai no Kansen [Ships of the World]***, September 2013. Ohara was a Japanese naval attaché in China in the mid-2000s.

[90] Qiao Yanfei, Yu Hui, Xiao Wu, and Jiao Jiancang, "To Have a Giant Ship Set Sail: Following the Journey of the Heart of Yang Lei, General Representative of a Military Representative's Office of the Shenyang Bureau of the Navy Armaments Department, in Supervising the Construction of the First Aircraft Carrier, Liaoning", ***Renmin Haijun [People's Navy]***, 18 June 2014.

stripped, which meant that the Chinese side had to provide all the weapons, combat systems, and other equipment required for an operational carrier.

While the refitting of the Liaoning took around 6-7 years and was one of the biggest programs in the Chinese shipbuilding industry's history, it was successful in addressing the numerous and complex range of tasks, many for the first time. The most difficult challenges included enabling the Liaoning to be able to conduct air operations, developing a reliable propulsion system, and supplying a full suite of electronic and combat capabilities. One technological issue that the Liaoning did not deal with, but will be important for the new generation of carriers reportedly already under development, is a catapult launching system.

The Liaoning represents a major step forward in the technological and industrial capabilities of the Chinese naval shipbuilding industry, but is a more modest advance for the operational capabilities of the PLAN. For the shipbuilding sector, the Liaoning was a critical learning experience that allowed them to proceed with more confidence and experience in building their first indigenous carriers. For the PLA Navy, the Liaoning provides a critical training platform to produce the first generations of pilots and deck crews that are able to conduct carrier operations. But it is only with the next generations of wholly domestically designed and built aircraft carriers that the PLA Navy will have a truly operational carrier capability.

This next generation of aircraft carrier arrived in the second half of the 2010s in the form of the Type 001A. This vessel represents an incremental innovation from the Liaoning in that it is of comparable size at around 70,000 tonnes and uses the same ski-jump flight deck although with a slightly more upturned deck. But the Type 001A does incorporate some important improvements, such as a better designed hanger, ship island, ammunition lift system, and more advanced information and electronics capabilities, including large-scale active phased array radars.[91] The Type 001A was launched in April 2017, began sea trials in May 2018, and is expected to go into operational service within another 12-18 months.

The PLAN and Chinese shipbuilding industry though does appear to be undertaking a far more ambitious technological leap with its follow-on model to the Type 001A. In February 2018, China Shipbuilding Industry Corporation (CSIC), the country's principal naval shipbuilder, issued an "Outline of Strategic Guidelines for High-Quality Development in the New Era" that pointed out that the company "should hasten the pace of achieving breakthroughs in the development of nuclear-powered aircraft carriers" as well as "new-type nuclear-powered submarines, quiet submarines, Artificial Intelligence-based unmanned underwater confrontation systems, 3D underwater defensive/offensive systems, and comprehensive electronic information systems for the naval battlefield" that should enable the PLAN to become a "deep-blue and distant-sea force by 2025."[92] Besides nuclear propulsion, there is also plenty of speculation that this new carrier will incorporate other cutting edge homegrown technologies such as electromagnetic aircraft launch system. Construction of the new carrier reportedly began at the Jiangnan Shipyard in Shanghai in 2017.[93]

The Chinese submarine acquisition program has also been undergoing a similar transition to indigenous sourcing. In the conventional domain, purchases of the Russian Kilo-class submarines in the 1990s and early 2000s have been superseded by the development and introduction into service of the Yuan and Song-class submarines, which are also armed with indigenous anti-ship cruise missiles such as the YJ-82 and YJ-18. The U.S. Defense Department points out though that the Chinese are still keen to seek Russian help in submarine development with a Sino-Russian joint design and production program based on

[91] "Advantages of China's First Domestically-built Aircraft Carrier", ***China Military Online***, 2 March 2018.
[92] "New Planning for New Journey: A New Era for High-Quality Development; What is in Store for CSIC? Guidelines Crystalize Direction", ***CSIC WeChat Account***, 27 February 2018.
[93] "China Has Started Building Its Third Aircraft Carrier, Military Sources Say", ***South China Morning Post***, 4 January 2018.

the Russian Petersburg/Lada diesel-electric submarine that has air-independent propulsion.[94]

China's missile industry, especially for ballistic missiles, has been one of the crown jewels of the country's indigenous defense science and technology development going back to the 'Two Bombs, One Satellite' era of the 1950s and 1960s. But some niche areas have benefited enormously from access to foreign, predominately Russian, assistance. This includes air-surface missiles (Kh-29T, Kh-59), surface-to-air missiles (S-300PMU, S-400), anti-ship cruise missiles (SS-N-22, SS-N-27B), and anti-radiation missiles (Kh-31P, Harpy). Even the DF-21 family of ASBM owes much of its initial design work to the U.S. Pershing II missile.[95]

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[94] Office of the Secretary of Defense, ***2015 Annual Report to Congress: Military and Security Developments Involving the People's Republic of China*** (Washington D.C.; U.S. Defense Department, 2015), p52.

[95] Andrew S. Erickson, ***Chinese Anti-Ship Ballistic Missile Development: Drivers, Trajectories, and Strategic Implications,*** (Washington DC: Jamestown Foundation, Jamestown Occasional Paper, 2013).

Challenges to Future Progress

The principal challenges that the Chinese defense industry faces to its continuing and long-term improvement stems primarily from its historical foundations and the uncertain efforts to overcome the corrosive legacy of its difficult past history. The institutional and normative foundations and workings of the defense industry were copied from the former Soviet Union's command defense economy and continue to exert a powerful influence to the present-day. The PLA and defense industrial regulatory authorities are seeking to replace this outdated top-down administrative management model with a more competitive and indirect regulatory regime, but there are strong vested interests that do not want to see any major changes.

The biggest constraints encountered by the Chinese defense industry and the PLA include the following:

- **Monopolies:** Little competition exists to win major weapons systems and defense equipment because each of China's six defense industrial sectors is closed to outside competition and are dominated by a select handful state-owned defense corporations. Contracts are typically awarded through single sourcing mechanisms to these corporations. Competitive bidding and tendering only takes place for non-combat support equipment, such as logistics supplies.
- **Bureaucratic Fragmentation:** This is a common characteristic of the Chinese organizational system[96], but it is especially virulent within the large and unwieldy defense sector. A key feature of the Soviet approach to defense industrialization that China imported was a highly divided, segmented and stratified structure and process. There was strict separation between the defense and civilian sectors as well as between defense contractors and military end-users, compartmentalization between the conventional defense and strategic weapons sectors as well as among the different conventional defense industrial sub-sectors, and division between research and development entities and production units. This severe structural compartmentalization is a major obstacle to the development of

[96] Kenneth Lieberthal and Michel Oksenberg, ***Policy Making in China: Leaders, Structures, and Processes*** (Princeton: Princeton University Press, 1988), 35-42. See also Kenneth Lieberthal and David Lampton (Eds), ***Bureaucracy, Politics, and Decision Making in Post-Mao China*** (Berkeley: University of California Press, 1992) and David Lampton (Ed), ***Policy Implementation in Post-Mao China*** (Berkeley: University of California Press, 1987).

innovative and advanced weapons capabilities because it requires consensus-based decision making that is carried out through extensive negotiations, bargaining, and exchanges. This management by committee is cumbersome, risk-adverse, and results in a lack of strong ownership that is critical to ensure that projects are able to succeed the thicket of bureaucratic red tape and cutthroat competition for funding. This entrenched bureaucratic fragmentation is a prominent feature of the armament management system. The GAD was only responsible for managing the armament needs of the ground forces, People's Armed Police, select space programs, and the militia.[97] The navy, air force, and Second Artillery have their own armament bureaucracies, and competition is fierce for budgetary resources to support projects favored by each of these services. This compartmentalized structure serves to intensify parochial interests and undermines efforts to promote joint undertakings. A major reform of the armament management system took place at the end of 2015 with the replacement of the GAD with the Central Military Commission Armament Development Department (CADD), which was part of a much broader effort to promote joint command, control, and operations and mitigate inter-service rivalries. [98] It will take some time to determine if these reforms will be successfully implemented, but the ability of the new CADD to carry out its mandate of providing centralized management of the armament system looks to have a greater chance of success than the GAD, which was hamstrung by its institutional bias towards the oversight of the ground forces. The nature of the relationship between the CADD and the armament departments belonging to the service arms will be critical in determining how much jointness versus compartmentalization there will in the PLA's armaments development.

- **Outdated Pricing Regime:** The lack of a transparent pricing system for weapons and other military equipment represents a fundamental lack of trust between the PLA and defense industry. The existing armament pricing framework is based on a 'cost-plus' model that dates to the planning economy, in which contractors are allowed 5 percent profit margins on top of actual costs.[99] There are a number of drawbacks to this model that holds back efficiency and innovation. One is that contractors are incentivized to push up costs as this would also drive up profits. Another problem is that contractors are not rewarded with finding ways to lower costs such as through more streamlined management or more cost-effective designs or manufacturing techniques. At the beginning of 2014, the GAD announced that it would conduct and expand upon pilot projects on equipment pricing. These reforms include the strengthening of the pricing verification of purchased goods, improving cost controls, shifting from singular to plural

[97] See Mao Guohui (Ed), ***Introduction to the Military Armament Legal System*** (Beijing; National Defense Industry Press, 2012), 46.
[98] "Ministry of National Defense Holds News Conference on CMC Administrative Reform and Reorganization," ***China Military Online***, January 11, 2016.
[99] Ibid, p158-159.

pricing models, from ‘after-purchase pricing’ to ‘whole process pricing’, and from ‘individual cost pricing’ to ‘social average cost pricing’.[100] These represent modest steps in the pricing reform process, but the PLA will continue to face fierce opposition from the defense industry on this issue.

- **Corruption:** This cancer has thrived with the defense industry’s uncertain transition from centralized state planning to a more competitive and indirect management model.[101] PLA leaders have highlighted the defense research, development, and acquisition system as one of a number of high-risk areas in which corruption can flourish along with the selection and promotion of officials, the enrollment of students in PLA-affiliated schools, funds management, and construction work.[102] The almost complete absence of public reporting on corruption in the defense industry and armament system means that the extent of the problem is not known. Military authorities justify this lack of transparency as many of the cases are likely to involve classified programs. In the anti-corruption crackdown that begun with Xi Jinping’s ascent to power at the 18th Party Congress in 2012, there have only been a handful of cases of defense industry executives and PLA armament personnel being arrested on corruption charges.[103] Maj-Gen. Li Mingquan, a former director of the General Purposes Armament Support Department in the GAD is the only publicized example of a senior GAD officer to have so far been swept up in the anti-corruption campaign.[104]

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[100] "Armament Work: It Is the Right Time for Reform and Innovation", ***Liberation Army Daily***, 13 February 2014.

[101] Corruption is defined broadly in China as covering the improper behavior of state, party, or military officials, but the more common Western definition is the abuse of public office for personal gain in violation of rules.

[102] “PLA Gets Tough On Duty Crimes”, ***Xinhua News Agency***, 1 December 2014.

[103] See, for example, “Wu Hao, Deputy General Manager of AVIC Heavy Machinery Under Investigation for Corruption, ***Xinjing Bao***, 4 June 2014.

[104] “47 PLA Generals Investigated This Year”, ***China Military Online***, 11 December 2015.

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From IDAR to Original Homegrown Innovation

The IDAR model has been the engineering launchpad for the Chinese defense establishment's takeoff for the past 1-2 decades and it will continue to play an influential role for years to come. But important segments of the defense industry are now beginning to transition from absorption to homegrown innovation. In the naval shipbuilding and aviation sectors, the types of innovation dynamics that are becoming more prevalent include crossover and incremental innovation.

There is evidence that more intermediate forms of innovation are also beginning to appear. The missile industry's development of the DF-21 family of anti-ship ballistic missiles is the prime example of architectural innovation. The primary enablers of architectural innovation are improvements in organizational, marketing, management, systems integration, and doctrinal processes and knowledge that are coupled with a deep understanding of market requirements and close-knit relationships between producers, suppliers, and users.

Under his tenure, Xi Jinping has laid out the key steps needed in turning China into an advanced defense industrial power. In his keynote speech at the Communist Party's 19th Congress in October 2017, Xi spelled out a timeline for China becoming a militarily powerful and technologically advanced country by the middle of this century. China should reach the first tier of the world's most innovative countries by 2035 and at the same time the military would realize its objectives of becoming a fully modern force. By 2050, China would challenge for global leadership with a world-class military a centerpiece of the country's "comprehensive national strength".

To achieve these highly ambitious goals, Xi provided a detailed set of reforms and initiatives that were required by the defense science and technology system: "strengthen unified leadership, top-level design, reform, innovation, and the implementation of major projects; reform the defense science and technology industry; achieve greater civil-military integration; and build an integrated national strategic system and capabilities”.[105]

One of the first priorities to be implemented is the strengthening of the defense science, technology, and industrial leadership system. This was carried out in 2016 with a far-reaching reorganization of the upper-most echelons of the PLA armament management system. To carry out Xi’s twin requirement of accelerating the pace of development and fielding of conventional armaments while at the same time pursuing more advanced, higher-risk, and longer-term research and development of next generation technologies, the PLA armament system has been restructured into two distinct parts.

The reform of the conventional weapons acquisition system saw the PLA General Armament Department (GAD) reorganized in 2016 into the Central Military Commission Equipment Development Department (CEDD). The emphasis is on more joint development programs compared to the ground force dominated focus of its predecessor. A more consequential overhaul has taken place in the management of the research and development of more strategic, cutting-edge, or revolutionary capabilities with the establishment of the CMC Science and Technology Commission (CSTC) that occurred at the same time as the CEDD was set up in January 2016.

When the CSTC was unveiled, there was considerable speculation in Chinese and foreign media that it was modelled on the U.S. Defense Advanced Research Projects Agency (DARPA). There are similarities in the functions of the CMC-STC and DARPA, of which one noteworthy example is that they both actively engage with civilian universities to support basic research.

But there are also important differences that suggests the Chinese approach in conducting disruptive innovation is distinctive from the U.S. model. A key difference is that the CSTC is tightly integrated into the PLA hierarchy with a

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[105] Xi Jinping, “Secure a Decisive Victory in Building a Moderately Prosperous Society in All Respects and Strive for the Great Success of Socialism with Chinese Characteristics for a New Era”, Report to the 19th Chinese Communist Party National Congress, ***Xinhua News Agency***, 18 October 2017.

two-star lieutenant-general in charge, whereas DARPA enjoys considerable autonomy by being outside of the uniformed chain of command. A CMC science research steering committee has also been established to provide technical and strategic guidance to the CSTC. These institutional developments demonstrate a clear commitment by the Chinese military authorities to seriously engage in higher-end home-grown innovation research and development.

Despite this impressive track record, the government is seeking to implement major reforms to overcome deep-rooted structural bottlenecks caused by the industry's central planning legacy. One important reform initiative that began in 2017 was a pilot project to overhaul the ownership structure of wholly state-owned defense research institutes and academies so they could be allowed to list. This would provide a lucrative source of capital as research institutes make up a significant proportion of defense corporations' fixed asset stock. Defense companies have been engaged in this process known as asset securitization since 2013 and have raised more than US$30 billion by the end of 2017 from initial public offerings and other financial vehicles that have been ploughed back into product development, including weapons activities.

Another important reform is the consolidation of state-owned defense conglomerates. Each of the half a dozen sectors that make up the Chinese defense industry is controlled by one or two of the country's big defense corporations. Efforts to promote competition in the late 1990s by dividing these monopolistic behemoths into two competing entities were largely a failure because of poor institutional design. Consequently, the Chinese authorities began to remerge these firms, especially so they can compete with much larger foreign firms on the global arms and technology markets. This began in the late 2000s with the consolidation of the aviation sector, but there was a long hiatus before the next merger took place at the beginning of 2018 between the two principal firms in the nuclear sector, China National Nuclear Corp. and China National Engineering Corp. The shipbuilding industry appears next in line for restructuring as one of its two dominant conglomerates, China State Shipbuilding Corp., has been adversely affected by a sharp downturn in the global civilian shipbuilding market.

The Chinese authorities have also been championing efforts to promote the convergence of the civilian and defense components of the national economy since the beginning of the 21st Century, but with little tangible success because of limited high-level leadership attention, unclear strategy, ineffective implementation, and poor coordination between civilian, defense regulatory, and military agencies. Chinese authorities see this convergence, which is termed civil-military integration (CMI), as essential in the country's drive for original innovation and defense modernization.

The bulk of efforts to promote CMI have focused on reforms of defense corporations and on the implementation of policies, platforms, and other mechanisms by which private sector technology can flow into defense projects. This included opening up the closed and opaque defense acquisition system to allow civilian firms to take part and bid for projects and reducing red tape and excessive secrecy.

Xi has actively promoted CMI under his tenure, which he rephrased as military-civil fusion (MCF 军民融合) to distinguish a new approach that he was taking. To address the previous CMI strategy that was ad hoc, structurally misaligned, and of low policy importance, Xi designated MCF as a national priority in 2015 and defined it as a development strategy. A central goal of the MCF development strategy is, according to Xi, to build an "integrated national strategic system and strategic capabilities". The development of such a strategic system and capabilities will allow China to "implement key science and technology projects and race to occupy the strategic high ground for science and technology innovation", Xi added.[106]

Key elements of this national strategic system are detailed in some of the MCF implementation plans that have been formulated since the adoption of the MCF development strategy. This includes the 13th 5-Year Special Plan for Science and Technology MCF Development issued in 2017 by the CSTC and the Ministry of Science and Technology (MOST) that detailed the establishment of an

[106] "Xi Calls for Deepened Military-Civilian Integration", ***Xinhua News Agency***, 12 March 2018.

integrated system to conduct basic cutting-edge R&D in artificial intelligence, bio-tech, advanced electronics, quantum, advanced energy, advanced manufacturing, future networks, new materials “to capture commanding heights of international competition”. This plan also noted the pursuit of MCF special projects in areas such as remote sensing, marine-related, advanced manufacturing, biology, and transportation.

The political significance of MCF gained even more prominence with the formation of the Commission for Integrated Civilian-Military Development (CICMD) in January 2017. The importance of this organization in leading MCF policy making and implementation was made clear with the appointment of Xi as its chair and Premier Li Keqiang as a vice-chair. At the CICMD’s first meeting in June 2017, Xi said that there was a “short period of strategic opportunity” to implement MCF, pointing out the most fruitful areas that included infrastructure, equipment procurement, training, military logistics, and defense mobilization.[107] In its September meeting, the CICMD issued a series of plans and guidelines tied to the 13th Five Year Plan on MCF that covered defense industrial development, and military logistics.[108]

[107] “Xi Jinping Addresses Meeting of Central Commission for Integrated Military-Civilian Development”, ***Xinhua News Agency***, 20 June 2017.
[108] “Xi Jinping Chairs Second Plenum of Central Integrated Military-Civilian Development Commission “, ***Xinhua Domestic Service***, -22 September 2017.

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Global Implications: Intensifying U.S.-China Technological Competition

China's pivot from re-innovation to original homegrown innovation is still in its initial stages but this shift looks set to grow faster, bigger, and better under Xi Jinping's long-term leadership. While major weaknesses will complicate progress, there are numerous sources of strength to mitigate or overcome these obstacles. They include ample funding and good access to foreign technology and know-how.

The rise of an increasingly innovative Chinese defense establishment has triggered deepening concern in the U.S. that its military technological superiority with China is under mounting threat. This has led to intensifying Sino-US defense technological competition that is likely to become more acute. The U.S. Defense Department has been pursuing a number of initiatives since the early 2010s in an effort to maintain its technological advantages, such as the Third Offset Strategy and the Defense Innovation Initiative that was pursued by the Obama Administration.[109]

While the Trump Administration no longer uses the Third Offset label, it has made clear that it embraces the view that the U.S. and China are now great power rivals. This is spelled out in the US national defense strategy issued in January 2018 that points out, "as China continues its economic and military ascendance, asserting power through an all-of-nation long-term strategy, it will continue to pursue a military modernization program that seeks Indo-Pacific regional hegemony in the near-term and displacement of the United States to achieve global pre-eminence in the future"

This competition in the defense domain has also spilled over into the broader U.S.-China technology relationship, especially in areas such as high and strategic technology, communications technology, U.S. and allied curbs on

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[109] See Tai Ming Cheung and Thomas G. Mahnken (Eds), ***The Gathering Pacific Storm: Emerging US-China Strategic Competition in Defense Technological and Industrial Development*** (Cambria Press, 2018).

Chinese investment in sensitive technological areas, and restrictions on research and development exchanges. The two countries appear to be spiralling into a technological cold war that has far-reaching negative consequences for not only their techno-security establishments but also for the development of their national innovation capabilities and for the global technological order as well.

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